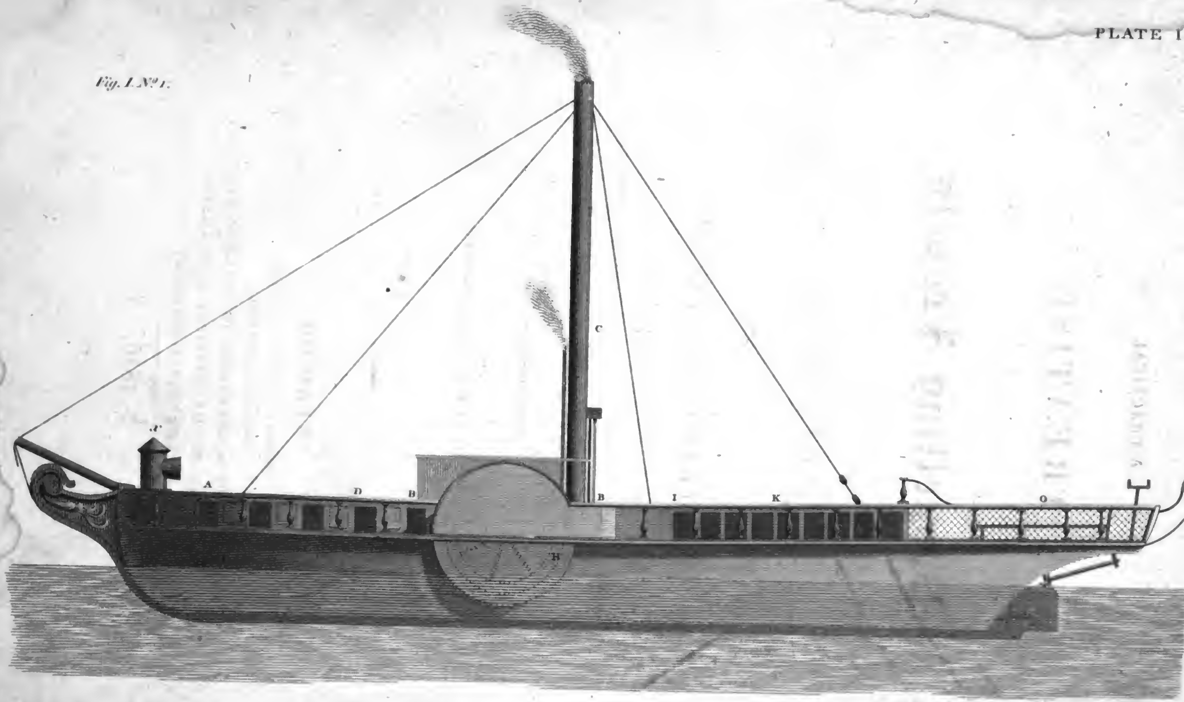
PLATE I.

Fig. I. Nº 1.



A PRACTICAL

# TREATISE

ON

# Propelling Vessels

BY

# *STEAM, &c.*

BY


ROBERTSON BUCHANAN,

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TREATISES ON HEATING AND DRYING BY STEAM, &c. &c. &c.


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*ILLUSTRATED WITH SIXTEEN ENGRAVINGS.*


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# PREFACE.

Navigation by Steam having been more early introduced and carried to greater extent on the Clyde than on any other river in Europe, and, ever since its commencement in this country, having engrossed much of my attention, I have presumed to lay before the Public the following Treatise on that subject. The utility of this invention requires no stronger proof than the rapid progress it has already made.

By increasing the velocity, certainty, and cheapness of conveyance, it may be regarded as producing the effect of diminishing distance, and thereby facilitating intercourse and promoting commerce.

Calculating from the progress which has already been made in navigation by steam, it is reasonable to suppose that it will rapidly extend not only in those countries

where it already exists, but that its benefits will be speedily experienced in every civilised nation.

From the length of time this Treatise has been in the press, from the progressive alterations and improvements in steam boats, and from my different avocations, I have been led to deviate somewhat from my original plan, and perhaps from that lucid order which is so desirable and proper, wherever it can be obtained.

After a short Introduction, I have, in the FIRST Part, stated the peculiarities of the Clyde navigation, and given an account of the various steam boats which have been employed on that river; and, for the use of those who have not previously paid attention to the subject of the steam engine, I have introduced a popular account and description of that useful invention.

The SECOND Part contains descriptions of various modes which have been, at different periods, proposed or tried for propelling vessels.

Part THIRD contains an account of steam navigation on other rivers in Great Britain and Ireland.

A short account of the steam boats in America will be found in the FOURTH Part; and, in the FIFTH, an account of the vessels propelled by means of machinery driven by cattle, which are employed on some parts of that continent.

The SIXTH Part is dedicated to subjects relating to the theory and practice of Naval Architecture. The intimate connection which this subject has with steam navigation, will, I trust, be some apology for the number of pages which it occupies, more especially as very loose notions are known to prevail among practical men with regard to the forms and other properties of vessels. If one vessel can be built of such a form as to have less resistance than another, it is equivalent to an increase of power in the steam engine, and that without expense of fuel. It is of importance too, in most rivers, that the steam boats should draw little water. Strength is an indispensable

quality in order to resist the stress occasioned by the action of heavy machinery, the motion of which is reciprocating as well as rotatory. As this Part is little more than a compilation, all I shall say of it is, that it cost me much time and pains in making such a selection as I thought would be useful to practical men. I have generally cited my authorities, and if I have in any instance omitted to do so, it has been in what may be found in a succession of Authors, and may therefore be esteemed as common property.

The experiments which are described in that Part, I hope will be acceptable to many who may not have before attended to them; and the recent improvements on ship-building made by Mr. Seppings and others, also here noticed, highly merit the attention of all who take an interest in improvements conducive to the safety of nautical property, and the health and lives of our seamen.

Part Seventh contains Miscellaneous Observations; some of which should, in strict order, have been introduced sooner; and

in Part Eighth is given additional information respecting steam navigation, which was obtained after Part Third was printed.

In the Appendix will be found some articles, to which allusion is made in an early part of the Treatise;—Mr. Murray's rule for calculating the weight of fly-wheels; a communication from Mr. Dryden, respecting steam engines; and an extract from the Proceedings of the Society for the Improvement of Naval Architecture.

If, after all the care I have taken to procure full and accurate information, I have, in any instance, failed, I hope due allowance will be made for the nature of the subject, and that it will be believed that it has been my desire to give an accurate statement of facts. The same motive influences me in the following short Narrative; in which I have attempted to bring into one view all that I could ascertain relative to the origin and early progress of navigation by steam.

Mr. Miller of Dalswinton, who made many models and experiments with a view

to the improvement of naval architecture, appears to have made the first attempt at working a vessel by steam. The vessel was double, with the paddle-wheel in the middle. The experiment however did not succeed to his satisfaction. About the year 1795, Lord Stanhope constructed a vessel, which I saw in Greenland Dock. The paddles were made in imitation of the feet of a duck, and were placed under the quarters; but the mechanism did not answer his Lordship's expectation. In the year 1801, Mr. Symington tried a vessel propelled by steam on the Forth and Clyde Inland Navigation, (see Art. 10,) but it was laid aside on account of the injury which it threatened to the banks of the Canal. I do not know that he ever tried this vessel on any river. In 1807, Mr. Fulton* of New York introduced steam boats in America, which were the first that succeeded in a profitable way †.

* Mr. Fulton died after a short illness at New York, on the 23d February, 1815.

† In the Monthly Magazine for October, 1815, Dr. Thornton of Washington, attributes the invention of Steam Boats in America, to Mr. John Fitch.

No farther attempts, in Great Britain, seem to have been made until the year 1812, when a steam boat, called the Comet, was tried on the Clyde. (See Article 12.) The merit of the introduction of steam navigation on the Clyde, has been claimed by two competitors, Mr. Henry Bell and Mr. W. Thomson; but the truth seems to be, that Mr. Bell hearing of what had been done in America, first thought of trying a steam boat on the Clyde, and that he was much assisted by Mr. Thomson in carrying his ideas into practice, the latter having been regularly bred a millwright and steam engine maker. Soon after this period, Mr. Theodore Lawrence of Bristol had a steam boat at work on the Avon, and carried her through the canals to the Thames; but, having been there opposed by the Company of Watermen, was obliged to take her back to the Avon. In 1813, a steam boat began to ply on the Yare, from Yarmouth to Norwich.

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A

# PRACTICAL TREATISE

ON

## Propelling Vessels,

MORE PARTICULARLY

## STEAM BOATS.

## PART I.

### INTRODUCTION.

1. It being impracticable for high-sided vessels, in a heavy sea, to make use of the common kind of oars, it was long wished to discover some method of propelling vessels independently of the wind. We accordingly find, that, from an early period, many projects for this purpose have been made public. Such, for instance, as 1st, a sort of oars always immersed in water, which folded up into a smaller space when

they were moved forward; 2dly, inclined planes placed behind the vessel, and moved by an alternate motion; 3dly, a species of screw entirely immersed in the water, by which water was elevated, and discharged behind the stern.

But to be more particular. M. Duquet appears to have tried revolving oars, so early as the year 1699, and experiments were made with them on a large scale, at Marseilles and at Havre. M. Camus, in the year 1703, proposed to work oars by machinery, in three different ways.

Martinot proposed, in the year 1763, to unite in one oar the properties of many.

In 1752, Daniel Bernoulli proposed the use of inclined planes immersed in the water, parallel to the sides of the vessel, which, turning in a collar, were moved in a plane, perpendicular to the keel.

In the *Annales des Arts*, vol. xx, a mode of impelling vessels without wind is proposed.

2. But as none of these modes were ever brought into practice, it is needless to enter farther into their detail.

I shall, therefore, proceed to speak of the modes in *actual use* for impelling vessels, without the aid of wind.

Vessels propelled by steam have been in use for some years in America, with great convenience to the public, and advantage to the proprietors; and the success which has already attended similar attempts in Scotland on the river Clyde, and in other places of this Island, has been such as to vindicate the opinion, that this mode of navigation will rapidly extend to other parts of the world.

As the probable success of working steam boats in a river, depends on a variety of circumstances, I shall, before proceeding to other subjects, state the peculiarities of the river Clyde, and describe various vessels that have been employed on it; but more minutely, those which have been found best suited to that river, leaving it to those interested in other situations, to judge how far these peculiarities may be applicable to their circumstances.

## SECTION I.

*The River Clyde.*

3. The usual voyage of the steam boats upon the Clyde, is between Greenock and Glasgow, a distance of about 24 miles by land, and about 26 by water.

4. The relative position of the different towns and villages on this part of the river, are as follows:

| | | | | |
|---|---|---|---|---|
| Glasgow, | | containing | 110,000 | inhabitants. |
| 6 miles | | to Renfrew, and 3 miles behind it, Paisley, - | 36,722 | inhabitants. |
| 9 | do. | to Kilpatrick. | | |
| 15 | do. | to Dumbarton, - | 3,121 | do. |
| 21 | do. | to Port-Glasgow, | 5,116 | do. |
| 24 | do. | to Greenock, - | 19,052 | do. |

5. Near Glasgow the river is very narrow, having been much contracted for the purpose of improving the navigation.

6. At Glasgow it is now only 140 feet wide, increasing about 4 feet every quarter of a mile, for the first two miles; the next

three miles, to 5 feet for every quarter of a mile, and so on.

7. At Dumbarton it is nearly two miles broad. At Greenock it widens to about five miles.

8. The fall on the river (measuring from the low-water mark at each place) from Glasgow, to Port-Glasgow is about 8 feet 6 inches.

9. The tides flow about 4 hours and 20 minutes; but much depends on the weather and the direction of the winds.

Neap tides, at Glasgow, are at most 3½ feet. Spring tides about 5½; and vessels drawing 9½ feet water, can come at ordinary spring tides to Glasgow.

The current here, during a high fresh, runs at the rate of about 4 miles an hour. The current of ordinary tides averages about 2½ miles an hour; but is strongest during the ebbing. There are many shallows in the river, particularly at Bowling Bay, 10 miles below Glasgow, near the junction of the Forth and Clyde Canals.

Here the deepest part of the stream at low water, was not, until of late, known to be greater than from 1 foot 6 inches to 2 feet 8 inches during dry seasons. Of late, however, in consequence of the formation of stone dykes, it has been increased to about 3 feet in depth. In common tides, the first turning at Port-Glasgow is 2 hours and 45 minutes earlier than at Glasgow.

## SECTION II.

10. So early as the year 1801, a vessel propelled by steam, was tried upon the Forth and Clyde inland navigation *, but was laid aside, among other reasons, on account of the injury it threatened the banks of the Canal by the agitation of the water. As far as I can learn, the same objection still subsists to the use of steam boats, on the usual construction, on artificial canals so narrow as those usual in Great Britain. That objection, however, I should think, does not apply to some of those of Holland, and other countries on the Continent.

* See Appendix, No. 1.

11. The first attempt, on any scale worthy of notice, at navigation by steam, on the river Clyde, was in the year 1812 *.

12. A passage boat (A †) of about 40 feet keel, and 10½ feet beam, having a steam engine of only 3 horses' power ‡ began to ply on the river, and continued until last summer; when, in consequence of want of power and too great draught of water, she could not come into competition with the boats which have been since introduced, and was therefore laid up.

13. In the month of March, 1813, another passage boat (B) was set agoing, 58 feet on deck, and 11 feet beam, with a steam engine of 10 horses' power. This vessel was very successful for a time, and very productive to the proprietor; but has since been superseded on the Clyde, by vessels

* The first steam boat in America was launched at New York, on October 3d, 1807, and began to ply on the river between that City and Albany.

† For the sake of perspicuity, each steam boat is distinguished by a letter of the alphabet, in the order in which they were brought into use.

‡ For the value of a horse's power, see Buchanan's Essay on Millwork, Teeth of Wheels, p. 130.

of greater speed and less draught of water. She now plies on the river Forth.

14. About midsummer of the same year, another steam boat (C) of 70 feet keel, and 75 feet on deck, and 13 feet beam, was also put in motion.

15. About the same time, another vessel (D) was tried, intended to carry goods as well as passengers. Her hull was well built and well suited to the navigation; but, from some defects in her machinery, she was not brought into full action till lately, when, having got new machinery, she was found last summer, with regard to steering well, and moving swiftly, on the whole, the best adapted to the Clyde, although her accommodation for passengers be inferior, and her draught of water greater than some others. It is, therefore, proper to note her dimensions; she is 69 feet from stem to stern, 15 feet 2 inches beam, and draws about 4 feet water.

16. Another vessel (E) of 80 tons burden, has for about 12 months been in motion.

The speed of this boat is about equal to that last mentioned; but those who have had experience on the river, are of opinion, that she is not so manageable in steering.

17. Besides three vessels that have left the Clyde, there are six at present plying on the river; two of which carry goods as well as passengers. They have, on the whole, been gradually increased in tonnage as well as in the power of their engines, and still larger boats and more powerful engines are constructing. Among others, one of about 90 feet keel, and 17 feet beam, with an engine of 24 horses' power; and one of equal burden, having an engine of 30 horses' power. These boats are all neatly fitted up, and some of them are elegantly decorated.

18. On account of the shallows in the river, one great object, is to construct the vessels to draw as little water as possible. Those built at an early period were, in this respect, very defective. Among the accompanying engravings, I have, therefore, thought it advisable, to give a plate of a

boat (G) which was constructed in a great measure with this particular view. She draws, with the usual number of passengers, 3 feet 6 inches. With the same view, the engine was made light, and to occupy the least space that could be devised. But from an over anxiety, with regard to these two last mentioned qualities, the engine was made of too small power, being only that of 8 horses; yet, notwithstanding this small power, she makes the average voyage within one quarter of an hour of the speediest vessel yet constructed, and which has an engine of 14 horses' power. This difference is attributed principally to the superiority of the construction and workmanship of the engines; as she has two of four horses' power each. Another reason for giving engravings of this vessel, is, that the accommodation for passengers is more convenient and elegant than any of the other steam boats yet afloat on the river Clyde.

19. The other boat (E) of which I have given engravings, is of a different mould, and also different in the internal arrangements; and one of the largest and most speedy

boats yet on the river. Hitherto she has been very advantageous to the proprietors.

20. On board all the boats are newspapers, pamphlets, books, &c. for the amusement of the passengers, and such refreshments as are desirable on so short a voyage.

21. The voyage betwixt Glasgow and Greenock, including stoppages at intermediate places, is commonly made in three or four hours. The vessels take advantage of the tide as far as circumstances will permit; but, as they start at different hours from the same place, they are sometimes obliged to go part or nearly the whole of their voyage against the tide.

22. The voyage has been accomplished in so short a period as two hours and a quarter, the tide being favourable, but against a moderate breeze of contrary wind.

23. On the 17th of November 1814, it blew a very strong gale from the S. W. One steam boat went and returned in that one day, although there was a heavy sea in

the lower part of the river, and a strong current in the upper part, occasioned by a heavy fresh. The same day, another of the steam boats carrying sail, was dismasted, and could not proceed on her voyage; the mast serving in these boats the double purpose of carrying sail, and acting as a smoke-chimney to the steam engine. The first-mentioned boat was stopped a considerable time, in order to tȧke on board the passengers of the second. Notwithstanding this hinderance, and the resistance from the fresh, she accomplished the voyage upwards, in three hours.

24. The time which was allowed to the mail coach to go between these towns, was three hours and a half; but, owing to extraordinary exertion, some of the coaches now run that distance in about two hours and a half.

25. Owing to the novelty and apparent danger of the conveyance, at the outset the number of passengers was so very small, that the first steam boat could hardly clear her expenses; but the degree of success

which attended that vessel, soon engaged public confidence. The number of passengers which now go in these boats, may seem incredible to those who have not witnessed it. Traveling by land has not only been in a great measure superseded, but the communication very greatly increased, owing to the cheapness and facility of the conveyance. Before the introduction of steam boats, the whole number of passengers in the common passage boats, did not, it is supposed, even in summer, exceed 50 up and 50 down, and those generally of the lower classes of the people. The number that then went by coaches, has been estimated at 24 persons up, and the same number down. But now, in fine weather, it is no uncommon thing for 500 or 600 passengers to go and come in the same day. One of these boats alone, has been known to carry 247 at one time.

26. In the summer, the pleasure of the voyage, and the beauty of the scenery, attract multitudes; and the bathing places below Greenock, have, in consequence, been crowded beyond former example.

The scenery near Glasgow is mild and beautiful: it becomes bolder and more picturesque as the river descends, untill it terminates in the rugged mountains of the Western Highlands.

Before proceeding to describe the particulars of the steam boats which ply on the Clyde, it may not be improper to give a general account and description of steam engines, for the information of those who have not hitherto paid particular attention to the subject.

## SECTION III.

### *Steam Engines.*

27. The invention of the steam engine is usually ascribed to the Marquis of Worcester. It is said that while a state prisoner in the tower of London, when some food was preparing on the fire of his apartment, the cover, having been rathe. tight, was, by the expansion of the steam, suddenly forced off and driven up the chimney. This circumstance attracting his attention, led him to a train of thought, which terminated in this important invention, obscurely

exhibited in his "Century of Inventions *," but carried into effect by Captain Savery †.

28. The principles and mode of operation of Captain Savery's engine, were the following. A suction-pipe having a valve at the top opening upward, communicated with a close vessel of water, not more than thirty-three feet above the level of a reservoir. The steam being thrown on the surface of the water in the vessel, forced it to a height as much greater than thirty-three feet, as the elasticity of the steam is greater than that of the air; and the steam being condensed by the injection of cold water, a partial vacuum was formed, and the vessel filled with water from the reservoir by the pressure of the atmosphere. The steam being admitted as before, this water was also forced up, and so on successively.

29. About the same period that Captain Savery was going forward with his engine in England, M. Papin at Marbourg in Ger-

* Published about the latter end of the reign of Charles II. Printed at London, in 1663.

† See Appendix, No. 2.

many, and M. Amontons in France, were engaged with a similar invention.

30. As the machines of M. Papin were not comparable with those of Captain Savery, and as very little was done on the subject by M. Amontons, the English nation is undoubtedly entitled to the honour of this happy discovery, as is most impartially stated by M. Belidor, in his Architec. Hydraul. tom. ii. liv. iv. chap. iii.; where he speaks to the following effect: "Although the Marquis of Worcester was the first in England who mentioned, in intelligible terms, a machine for raising water by means of fire, in a small tract, entitled 'A Century of Inventions,' yet we cannot deny Captain Savery to have been the first who executed those sorts of machines in Great Britain. This is attested by many letters wrote to me on that occasion, by the gentlemen of the Royal Society there; in one of which, mention is also made of Mr. Newcomen's having contributed very much to bring it to its present perfection. Another proof that this machine took birth in England, and that it excels every other of the kind

that hath been tried in France and Germany, is, that all the fire engines that have been constructed abroad, have been executed by Englishmen."

31. The next step in the progress of improvement in steam engines, was made by Mr. Newcomen, an Ironmonger, and John Calley, a Glazier of Dartmouth, about the year 1711. Its principles were the following:

If steam be admitted into the lower extremity of a hollow cylinder, to which a piston is adapted, the piston will be forced upwards by the difference between the elastic forces of the steam and the atmosphere; and the steam being then condensed, the piston will descend by the pressure of the atmosphere, and so on successively.

This is sometimes called the atmospherical engine, and is commonly applied to work one or more pumps, by means of a lever or beam.

In the engines hitherto described, there was a very great loss of effect, occasioned by the steam cylinder being so much cooled by the injection-water, &c. but happily,

Mr. Watt discovered a remedy for that evil, and by means of this improvement, Britain has been enabled to extend and improve her manufactures, under many adverse circumstances, to a degree beyond the expectation of the most sanguine.

32. The great features of the improvement made by Mr. Watt on the engine of Newcomen and Calley, are, first, that the elasticity of the steam itself, is used as an active power; and, secondly, that, besides various other arrangements for the economy of heat, he condenses the steam not in the cylinder, but in a separate vessel.

Mr. Watt's first experiments were made in the college of Glasgow, with a model which he was repairing, belonging to its philosophical apparatus. He obtained a patent for his invention in the year 1769; but having had to struggle with many difficulties, which prevented him from being remunerated by his patent, the exclusive privilege was, for that reason, and on account of the merit of the invention, renewed by Parliament.

An idea of Mr. Watt's engine may be thus formed. Suppose a cylinder and piston similar to that of Newcomen, (see Art. 31.) and let the upper end of it be closed, and the piston-rod allowed to slide air-tight through a collar in the cover. The steam is conveyed from the boiler through a pipe to the upper part of the cylinder, and communicates occasionally to the lower part, and beyond that space, with a vessel, (the condenser,) in which the condensation is performed by an injected stream of cold water, which is drawn off by a pump.

By means of valves, the steam is made to act alternately above and below the piston; while a communication is opened on the opposite side of the piston with the condenser. The elastic force of the steam thus acting on one side of the piston, while there is a vacuum on the other side, produces an alternate motion, which is communicated by the piston-rod to the lever or beam, on the opposite end of which there is suspended the connection-rod which moves a crank and fly-wheel, in the same manner as the domestic spinning-wheel receives its motion.

For many years, instead of the crank, Mr. Watt used what are called *sun and planet wheels*, the one working round the other; which causes the fly perform two revolutions for each stroke of the engine.

Mr. Watt was induced to use this contrivance at first, in order to evade the crank, for the application of which, to produce a rotary motion in steam engines, a person in Birmingham, without Mr. Watt's knowledge, had obtained a patent, at a time when Mr. Watt's other avocations took off his attention from this particular part of the machinery of his engine, although he had originally intended to use the crank.

Mr. Watt is still of opinion, that when the wheel-work and the rest of the apparatus is accurately executed, and kept in good repair, that the sun and planet wheels possess advantages over the crank, particularly in regard to the greater velocity of the fly-wheel, which obviously requires much less weight.

33. The foregoing description being understood, it will not be difficult to comprehend the construction of what are called

high-pressure engines, for a modification of which, Mr. Trevithick obtained a patent.

Suppose the condenser taken away from Mr. Watt's engine, and very strong steam used, which instead of being condensed, is allowed to escape freely from the one side of the piston, while it is acting forcibly on the other; then, an alternate motion will be produced in a very simple manner, and that motion is communicated to a fly-wheel, by the intervention of rods, levers, &c.

34. An idea of Mr. Woolf's engine may be formed, by supposing Mr. Trevithick's engine connected with Mr. Watt's, in such a manner, that, instead of allowing the steam to escape into the atmosphere, it may pass into the cylinder of the engine on Mr. Watt's principles; the first cylinder being much smaller than the second. Mr. Woolf uses (like Mr. Trevithick) strong steam in the smaller cylinder, which is allowed to expand itself into the second cylinder, and may be thus said to act twice. Both cylinders are enclosed in casings filled with steam, as hot as that which enters the smaller cylinder. The latter is supplied with steam from the casing.

To enter into all the modifications of the steam engine, would require volumes. What I have said will, I hope, serve the present purpose *. See Appendix.

## SECTION IV.

### *General Description of the Steam Boats on the River Clyde.*

35. A variety of modes for propelling vessels, by the power of steam engines have been projected, and many of them tried; but those on the Clyde have their machinery all constructed on one general plan; namely, that of having paddle-wheels, (similar to undershot water-mill wheels,) on each side of the vessel, which are put in motion by the steam engine.

36. In some of those wheels the paddles are placed at right angles to the plane of their sides; in others, they are placed obliquely; and in others, they are curved. But it is not yet ascertained which is the

* The Marquis of Worcester's 'Century of Inventions' was republished with an Historical Account of the Steam Engine for raising Water, by Mr. John Buddle, (father of the present Mr. Buddle of Walsend,) at Newcastle, in 1813.

best form; for, although some boats move with much more velocity than others, it is difficult, where so many causes are in operation, to ascertain, whether any one of them singly produces that effect. Experiments are yet wanting to ascertain what number of paddles is best, or at what velocity they should move. It would probably be found of advantage, to have a power of changing the velocity of the paddle-wheels according to the circumstances of the current; for when the boat goes with the current, (the velocity of the paddles remaining the same in both cases,) the paddle enters the water comparatively at rest; whereas, when the boat goes against the current, the water is going in the direction of the motion of the paddle with great velocity.

The steam boat (E) has eight paddles; but, it is supposed, seven would be more effectual. It is evident, that when the water is much broken, there must be a loss of effect; for, let us suppose an extreme case, an indefinite number of paddles would become like a solid cylinder, which could have no effect in propelling the boat.

37. The paddle-wheels of the steam boat (E) are 8 feet 10 inches diameter, and 4 feet wide, and are calculated, when the engine makes 45 strokes per minute, to move, at the circumference, at the rate of thirteen miles an-hour. The paddle-wheels of the steam boat (G) are 9 feet diameter, and 2 feet 11 inches wide. This boat has 10 paddles.

38. The steam engine is placed near the middle of the length of the vessel, and the smoke is carried up in a plate-iron tube, which also serves the purpose of a mast, on which a sail is used when the wind favours. Before the engine, is the *steerage*, or *second cabin;* abaft the engine, is the *principal cabin.*

The principal cabin of steam boat (E) is heated by means of a pipe filled with steam*, which is placed under the seats.

The steam boat (G) has its cabin heated by means of a pump, which forces a current of air (heated by passing over a part of the

* For particulars on this subject, see Buchanan's Treatise on Heat Fuel, and Heating by Steam. Published by Messrs. Longman & Co. Paternoster Row, and Mr. John Underwood, Fleet-Street, London.

chimney) into the cabin. This last mentioned boat, in point of elegance in the interior arrangements, excels any yet on the river. Farther details of the boats will be best understood from inspecting the plates and references.

### 39. *Reference to the Engravings of Steam Boat G, Fig. I.*

Fig. I. No. 1. An elevation or side view, showing one of the paddle-wheels.

Fig. I. No. 2. Longitudinal horizontal section.

Fig. I. No. 3. Longitudinal vertical section, showing the interior of the cabins and machinery.

Fig. I. Nos. 4 and 5. Transverse sections.

#### *General Reference to Fig. I.*

A, the fore cabin.

BB, space for the machinery.

C, the iron chimney, serving also as a mast.

D, the steward's room.

F, the boiler, which contains the cylinder of the two steam engines.

GG, the steam engines *.
aa, the cylinder.
bb, the beams.
cc, the air pumps.
HH, the paddle-wheels †.
I, the ladies' cabin.
K, the principal cabin.
LLL, stairs to the cabin.
MM, water-closets.
NN, gang-ways.
O O, seats at stern and on deck.
P, the rudder.

40. Considerable inconvenience have been experienced in some of the steam boats, from the difference of draught of water between the light vessel, and when fully laden with passengers or goods. This is owing to the centre of the paddle-wheel remaining at the same point in the vessel; the wheels, of course, work much deeper in the water when the vessel is laden than when light. To remedy this, the following contrivance

* These engines make 45 strokes a-minute; length of the stroke, 22 inches.

† These paddle-wheels are 9 feet diameter, 2 feet 11 inches wide. They have 10 paddles, and make 30 revolutions a-minute; 14.1 feet a-second, or nearly 10 miles an-hour.

was adopted for the steam boat G, and it has been found in practice, completely to answer the proposed end.

*Fig. I. Nos.* 6 *and* 7.

The paddles AB, AB, &c. instead of being fixed to the shrouding CDEG of the paddle-wheel are made to slide between guides, at pleasure, outward or inward; which is done by means of a rack, HHH, &c. connected with each paddle, which is worked by a toothed-wheel I, movable round the axle of the paddle-wheel. Attached to the toothed-wheel, is a toothed-segment, K, adapted to which there is a pinion L, fixed on a spindle MN, which turns at each end in bushes fixed to the arms of the paddle-wheel.

All that is necessary to be done, therefore, in order to make the paddles work more or less deep in the water is, when the paddle-wheels are at rest, to turn, by a key or wrench, the spindle MN, which, by means of the intermediate parts, above described, causes the paddles to recede from, or approach to, the centre of the wheel.

41. *References to the Engravings of Steam Boat E, Fig. II.*

Fig. II. No. 1. An elevation or side view, showing one of the paddle-wheels.

Fig. II. No. 2. Longitudinal horizontal section.

Fig. II. No. 3. Longitudinal vertical section, showing the interior of the cabins and machinery.

Fig. II. No. 4. and Fig. I. No. 5. Transverse sections.

*General References to Fig. II.*

A, the fore or second cabin.
BB, space for the machinery.
C, the iron chimney, serving also as a mast.
D, the boiler.
EE, the steam engine.
G, the crank.
H, the fly-wheel.
II, the paddle-wheels.
K, ladies' cabin.
L, steward's room.
M, principal cabin.
NN, stairs to the cabins.
OO, water-closet.

PP, &c. gang-way.
QQQ, seats at stern and on deck.
R, the rudder.
S, covering of paddle-wheels.

*Observations on the Navigation of the Clyde.*

42. From the preceding narrative it will appear, that the boats have gradually increased, as well in dimensions, as in power of steam engines; experience having shown that large boats with powerful engines are the most advantageous. Small vessels are worked nearly at as much expense as larger ones, while they cannot carry a sufficient burden to make them profitable. It has been farther experienced, that large vessels with powerful engines have, in point of celerity, greatly the advantage over small ones.

In America, accordingly, we find that the steam boats are of great burden; the magnitude of the rivers in that continent, rendering very large vessels perfectly manageable.

In such comparatively small rivers, however, as the Clyde, steam boats of very great burden cannot be navigated with

safety; because the longer the vessel is, the more room she requires in turning out of the way of any other vessel or obstacle which may occur. It has been already noticed (Art. 15.) that a boat (D) 69 feet from stem to stern, 15 feet 2 inches beam, has been found best adapted to the Clyde. Taking this vessel, then, as a model of the best proportion, for breadth and length, of a vessel for the river Clyde, an inference may be drawn as to the dimensions of a boat proper for any other river, whose breadth and trade are known.

43. It may farther be observed, that steam boats, as hitherto constructed, are less easily turned, than vessels impelled by sails only. The tendency of the wheels acting so near the centre line of the vessel, is to propel her straight forward; whereas, in turning a sailing vessel to the wind, the sails aid her in coming about; and even common oars, act so far out from the side of the vessel, that they have much more power to bring her round, than the wheels of a steam boat can possibly have.

44. The hull of the vessels ought to be made very strong, particularly where the machinery is placed. The steam boat (G) is built of fir, and has a flat bottom and square in the bilges, like the *bateaus* in Canada; but, however flat the vessel, it is better to have the bilge a little rounded. I would also recommend oak instead of fir.

45. A most important point is to have a good steam engine. Those used on the Clyde having what are called bell-cranks below, instead of a beam working above, are found to strain the vessels. Those having the beam above, work much more steadily. All the engines hitherto used on the Clyde, have been made on Mr. Watt's principle. See Art. 32.

46. The boiler when placed on one side of the vessel is also very objectionable, because any change in the quantity of water in it, causes the vessel *to heel.*

In steam boat (G) the boiler extends from side to side of the vessel, which is a much better mode, and not liable to the above objection.

47. With respect to steam boats for conveying goods as well as a few passengers, it is found that a vessel (H) whose dimensions are 65 feet keel, 18 feet beam, and 90 tons burden, is well suited for that purpose: on the river she makes from two to three trips weekly. Vessels for this purpose, should be well manned, or at least, well attended at the ports, in order that little time may be lost in loading and delivering the cargo.

48. Since the foregoing was written, two new steam boats have been put in motion. The one (I) about 85 feet keel, and 16 feet beam, with an engine of 24 horses' power; and the other (K) about 90 feet keel, and 16 feet beam, with 32 horses' power. The steam boat (D) (see Art. 15.) of 14 horses' power, goes, at an average, about 6 miles per hour in dead water, which is as fast as either of those two vessels mentioned above. June, 1815.

49. That the increase of the velocity here, has not been in proportion to the increase of the power of the steam engines.

will not be surprising when it is considered that the resistance to which a boat is subject, increases not in an arithmetical proportion, (as, 1, 2, 3, 4, 5, &c.) but in a geometrical proportion, *viz.* as the squares of velocity, (as, 1, 4, 9, 16, 25). In other words, to make the same vessel move with ten times a given velocity, requires one hundred times the power.* And it is farther to be considered, that the more powerful engines, above mentioned, are heavier, which requires a greater floating body to support them, and of course, increases the resistance.

50. Besides three vessels that have left the river, and one laid up for repair, ten at present (August, 1815) ply on the Clyde. Until this summer, the regular voyage of the steam boats was limited to Greenock, a distance of 26 miles from Glasgow; but they now go regularly as far as Ayr (about

* On railways, an increase of velocity requires only an arithmetical increase of power, or, in other words, to draw a carriage on a railway with ten times a given velocity, would require only ten times the given power. See Edgeworth on Roads and Carriages, p. 38. As a farther illustration, it has been said, that the *ice boats* in Holland have been known to cross from Amsterdam to Saardam, at the rate of 48 miles an-hour.

64 miles from Glasgow, by the river) on the one side, and to Inverary on Loch Fine, which branches from the other side of the river. I mentioned that three steam boats had left the Clyde: one went, last winter, through the Forth and Clyde canal, and thence to the Thames, where she now plies between London and Gravesend; another vessel, too large to get through that canal, went round the Land's End to the Thames, and on her passage, twice crossed the British channel, and now plies between London and Margate; the third is on the Mersey, where she now plies between Liverpool and Runcorn.

The Prince of Orange steam boat arrived at the quay of Paisley, on the evening of Tuesday, the 25th of July, and sailed next morning, with passengers, for Greenock and Gourock. This having been the first steam boat that had sailed up the Cart, a vast crowd of people assembled to witness her arrival at Paisley.

51. In any sea which the vessels on the Clyde have had yet to encounter, they have found little hinderance, either from a head

sea or a following sea; but when the sea was on the beam they did not work so well as in the other cases.

52. The cost of a steam boat is a natural inquiry. Some idea of it may be formed from the following statement respecting the steam boat, (G,) one of those of which engravings are given.

| | |
|---|---|
| The hull, - - - - - | £ 700 |
| Steam engine, and all other machinery, cost £1000; about £700 of which, went for the steam engine, the rest of the sum, about £300, was laid out for the paddle-wheels, and connecting machinery, - | 1000 |
| Joiner's work, - - - | 200 |
| Upholsterer's work, - - - - | 70 |
| | £1970 |
| Contingent Expenses, - - | 330 |
| Total, - - - - - - | £2300 |

The hull was built at Port-Glasgow, and the steam engine, with all the rest of the work, was executed at Glasgow.

53. Another very natural inquiry, is, the expense of working such a steam boat. Some idea of this may be formed from the following statement of the number of hands usually employed in those carrying *passengers* only:

| | Persons |
|---|---|
| Captain, - - - - - - | 1 |
| Pilot, who steers the vessel, - - | 1 |
| Engine-man and assistant, - - | 2 |
| A seaman, who has usually one assistant, | 2 |
| The steward and assistant, - - | 2 |
| Total, | 8 |

*N. B.* Those carrying *goods* have usually only five hands.

54. With regard to fuel, it being obviously much more difficult to have every thing kept in proper order in a boat, where the engines are commonly much confined for space to contain and work them, than a-shore, a greater waste of fuel takes place. The quantity hitherto used in the steam boats on the Clyde, has been much greater than the usual allowance for Messrs. Boulton, Watt, & Co.'s steam engines. For one

of 14 horses' power, a-shore, they allow 1 cwt. 1 qr. 20 lb. per hour, of good Newcastle coal; but Glasgow coal is much weaker. One of the boats with an engine of 33 horses' power, requires 3 tons 12 cwt. from Glasgow to Gourock, fully 29 miles, and back to Glasgow. One of 15 horses' power, and another of 8 horses' power take each the same quantity, *viz.* from Glasgow to Greenock, (26 miles,) and back to Glasgow, 1 ton 4 cwt.

Having said thus much respecting the navigation of the river Clyde, before proceeding to mention what is doing on other rivers, (which increases while I write,) I shall describe several other contrivances besides paddle-wheels already described, which have been tried or proposed, for propelling vessels by steam.

## PART II.

### OF OTHER MODES WHICH HAVE BEEN TRIED OR PROPOSED FOR PROPELLING VESSELS BY STEAM.

### INTRODUCTION.

55. It may be useful to inquire into what has hitherto been proposed or attempted for the purpose of propelling vessels by steam. Bringing a variety of hitherto scattered contrivances thus into one focus, may possibly, even to the well-informed mechanic, suggest new ideas, or lead to useful investigations; while it may prevent the ingenious, but partially-informed and unexperienced, from wasting time and money in trying experiments, which have been long before tried and found ineffectual: for it is not less true in mechanics than in morals, that "a little knowledge is a dangerous thing." *Negative knowledge*, if I may use the expression, is often as useful as positive knowledge, or, in other words, to know what will *not* answer may save much time, trouble, and expense, and, of course, shorten the way to the object of pursuit.

## SECTION I.

56. Dr. Franklin in his "Maritime Observations," p. 113, speaking of various means of giving motion to a boat, says, "that of M. Bernoulli appears one of the most singular, which was, to have, fixed in the boat, a tube in the form of an L, the upright part to have a funnel-kind of opening at top, convenient for filling the tube with water, which descending and passing through the lower horizontal parts, and issuing in the middle of the stern, but under the surface of the river, should push the boat forward." Dr. Franklin then suggests some improvements, needless to be here detailed, as machinery, nearly on the same principle, was reduced to practice by the late Mr. James Linaker, master mill-wright of his Majesty's yard, Portsmouth. I am indebted to his successor, Mr. Kingston, for the use of the original papers and drawings.

57. Mr. Linaker, as appears from some of his memorandums, so early as the year 1793, made a set of experiments on propelling a vessel by means of machinery, but

did not obtain a patent untill 1808. He had two different plans: the one was to work pistons horizontally in pumps, drawing in the water at the bow, and discharging it at the stern of the vessel.

58. The other plan was to work a vertical pump in the middle of the vessel, drawing the water in at the bow, and expelling it at the stern. This idea he put in practice on a considerable scale, and had a steam engine constructed by Messrs. Fenton, Murray, and Wood, of Leeds; but I am uncertain whether he lived to try it on board his boat. The engine is now employed to drive turning lathes, &c. in the mill-wright's shop in the dock-yard at Portsmouth.

59. From one of Mr. Linaker's papers, without a date, it appears that he had tried a boat on the first plan. "It was a heavy boat, 31 feet long, and 6 feet wide; and though it had but one trunk, which was much against the uniformity of the motion, it moved nearly 4 miles an-hour, with 8 men working about 30 strokes per minute; 6 men

worked about 25 strokes per minute, and moved at the rate of 3 miles an-hour. The length of the stroke of the bucket was 6 feet. The inside of the trunk, 5 inches by 15, which the bucket filled. When the valve was open the water-passage was very free, the metal being cast thin. The trunk had its sides parallel from end to end." See Fig. 3.

60. I have been informed, that when the second plan, *viz.* the vertical piston, was tried, the motion of the vessel was far from being uniform, and that it went by jerks at each stroke of the pump.

61. It occurs to me that this fault might, in a great measure, if not entirely, be remedied by the use of air-vessels connected with the pump, which, as is well known, would counteract the effect of the *vis inertiæ* of the water, and cause the stream of water to act nearly as if it were continuous.

It is to be regretted that Mr. Linaker did not live to try this plan more fully; for, allowing it to be as effectual as that of paddle-wheels, it is certainly much better

adapted for use in rough water, and would be well suited to vessels going farther out to sea than has yet been regularly attempted. It is to be hoped that his successors may be encouraged to make some farther trials.

*Description of Mr. Linaker's First Plan.*

62. Suppose a square wooden common pump to be floating horizontally, with the handle upward, and worked in that situation: the drawing in of the water at the one end, and forcing it out at the other, would have a tendency to move the pump in a direction contrary to the water passing through it. This state of things being understood, will give an idea of Mr. Linaker's first plan. The engravings of Fig. III. No. 1, 2, and 3, represent the machine as actually constructed.*

AA, the boat.
BB, the trunk pistons.
CC, the trunks.
DD, the trunk piston-rods.

* It may be proper to mention, that the same things are marked with the same letters in all the elevations, plans, and sections, of the same object, in this Treatise.

EE, levers connected with these piston-rods, and to which motion is communicated from the steam engine K, by

GG, the rods, and

H, the tumbler.

*Description of Mr. Linaker's Second Plan. Fig. IV. No.* 1, 2, *and* 3.

63. AA, the boat. BB, the steam engine. CC, the boiler formed of wood to contain the water and steam, with iron flues to contain the fire. DD, an iron chimney. EE, a large cylinder, connected with two horizontal trunks. II and MM, have valves in them, and form a large double pump; the piston (F) of which, being moved by the steam engine, will, on its ascent, supposing the air previously expelled, draw water at the valve G, in the trunk MM, and force water out at the valve H, of the trunk II.

Again, the descent of the piston F, will draw water by the valve K, in the horizontal trunk II, and force out water at the valve L, in the trunk MM. By means of this alternate expulsion of the water from the trunks, the boat is propelled forward.

64. For reversing the motion of the vessel, there are a double set of valves; and by means of the keys NNNN, the one set are raised up out of the water-passage of the trunks, while the others are disengaged, and allowed to act.

*Observations.*

65. It was already mentioned (Art. 61) that the use of air-vessels connected with the pump, would probably be of great service in equalising the motion, saving power, and increasing the velocity of the boat. These air-vessels, I think, might be placed with advantage between the foremost valves, and the vertical parts of the pump. But in whatever way a boat is propelled, in endeavouring to find a point of resistance, a considerable part of the force employed, will be lost in repelling the water backwards.

66. Since the death of Mr. Linaker, a plan on a similar principle, had a partial, but imperfect, trial on the Thames. The steam engine had no piston, but drew in the water, and expelled it on the principle

of the old engine, known by the name of Savery's. See Art. 28. By this plan, although possessing the advantage of simplicity, there was, as is well known, a great waste of fuel. Attempts have been made to improve Savery's engine, which might become worthy of more attention, were the plan of propelling vessels by means of the general principle which was kept in view by Bernoulli, Franklin, and Linaker, adopted.

67. The plan of moving vessels in imitation of sculling has been proposed, and seems to promise considerable advantages; but I do not know that it ever has been tried, at least by the agency of steam.

68. Experiments have been made on a kind of screw; but this, I believe, after a trial on a considerable scale, in America, was rejected. Some mechanics, however, still think favourably of it, and suppose that if a screw of only one revolution were used, it would be better than where a longer thread is employed.

## SECTION II.

69. A plan of propelling vessels by steam, which seems to have occurred to many, is that of having a chain, with a number of paddles attached to it, going over two wheels, one of which being put in motion by the engine, communicates motion to the chain and to the other wheel. The lower part of the chain is near the water line of the vessel, and the paddles projecting down into the water, continue to act on it from the time they leave the lower extremity of the one wheel, until they arrive at the lower extremity of the other, in a vertical position. This mode is represented in Fig. V. in which AA are the wheels, BB the chain, aaa, &c. the paddles.

*Observation.*

70. However plausible this mode may seem, it was found, upon trial on the Duke of Bridgewater's canal, not to give satisfaction. The friction of heavy chains, and so many parts exposed to injury, are obvious objections to this plan.

There is a model of a vessel having an apparatus of this kind, in the *Galerie des Machines* at Paris.

## SECTION III.

71. Another mode which has been made in model, but never, that I know of, tried on a large scale, is represented in Fig. VI. in which AA are cranks, (moved by the internal machinery,) which are both connected with the horizontal beam BB, to the under edge of which, there is attached a number of paddles aaaaa.

### *Operation.*

72. While the cranks revolve, they carry the beam always parallel to itself, producing at the same time, a reciprocating motion. During one part of the revolution of the cranks, the paddles are out of the water, and during another, they act against the water, and propel the boat.

### *Observation.*

73. However simple and ingenious this plan may be, it has a defect which renders it useless for the purpose intended, namely,

the motion of the paddles in entering, and at leaving the water, is so exceedingly slow, compared with its motion in the middle between these extremes, that unless it went at a speed too great in the middle part, it would retard the boat at both extremities of the motion of the paddle in the water, which, I hope, will be made clear by the following illustration.

From inspecting Fig. VI. No. 2. it will appear that the extremities of each of the paddles must revolve in a circle, and act like a number of small paddle-wheels, having their paddles in a state of parallelism, working very deep in the water.

Suppose Fig. VI. No. 3. to represent such a paddle-wheel, and aaaaa equal parts of the revolution of the paddle; if perpendiculars from those points, fall on the line XY, they will mark the progressive motion of the paddle in the water, which is evidently very slow in the first division, compared with what it is in the sixth.

## SECTION IV.

74. While engaged in making a model of the mechanism described in the forego-

ing section, and considering its defects, my attention was directed to endeavour to improve the common paddle-wheel, by producing parallelism in the paddles, in order that they might act in a vertical position. This effect I first produced by wheel-work of various combinations, some of which had existed (although at first it did not occur to my recollection) long before in the machinery of orreries. The first construction I adopted was the following.

Let A, B, and C, Fig. VII. No. 1. be three spur-wheels, each having the same number of teeth. If the wheel A be stationary, and the wheel B and C made to revolve, each round its own centre, while they revolve around A, and the teeth of the three wheels act into one another, the line *a b* which may represent a paddle, will continue parallel to itself in every part of the revolution. For instance, suppose the wheels to have moved untill their arrival at the situation represented by dotted lines, the line *a b* will still be parallel to its first situation. Suppose, then, one such wheel, A, (see Fig. VII. No. 2 and 3,) fixed in the centre, and several pair of wheels similar to

BC, adapted to work into it, and a paddle attached to the axle of each wheel C, then the paddles would remain parallel to their first situation in each part of their revolution; and, consequently, if they were all placed in a vertical position, they would remain so.

Other combinations of wheel-work produce the same effect, of which that represented in Fig. VIII. is an instance, and which will be easily understood by inspecting the figure, without farther description. But as it is not probable that any combinations of wheel-work for the purpose will ever be brought into practice, I presume it is unnecessary to enter farther into their detail.

75. In the models which I made, the wheel-work was defended from weeds and other matters, which might be in the water, by a cover. Upon duly weighing the disadvantages attending the employment of so much wheel-work, I directed my attention to endeavour to produce the effect of parallelism in the paddles by more simple means. This was accomplished in the manner I am about to describe, and, in drawings

and models, appeared to promise so much success on the large scale, that by the advice, and with the assistance, of some able mechanics, it was tried in a steam boat built for the purpose, and was in actual use for some time. I must, however, candidly state, that the particular mode in which the principle was applied for that purpose, was found to require too much accuracy of workmanship, and to be too liable to injury. It was, therefore, laid aside; but, for the reasons assigned in the Introduction to this part of the Treatise, I shall describe the principle on which the machinery was constructed.

76. As a proof that others had thought well of the principle, Mr. Wright of Yarmouth showed me a model of a paddle-wheel on the same principle, which he had adopted for a steam boat, that was then (June, 1815) nearly ready to be launched.

77. In the first place, this mode of producing parallelism in the paddles, without the aid of toothed wheels, is established upon a mathematical theorem, which may be enunciated in the following words.

*If two equal rings or circular lines in the same plane, or in planes parallel to each other, be conceived to revolve each upon its respective centre in its own plane, with one and the same uniform velocity, and in the same direction with regard to parts of the rings, or lines alike situated, and any point be taken in one of the rings or lines, and a right line be drawn from that point parallel to a line supposed to join the centres, untill it meets the other ring or circle, then the right line so drawn, will be equal to the line of distance between the centres, and will continue equal and parallel to that line of distance, during the whole of every revolution so made.*

Secondly, the dotted circle, and the black circle in Fig. IX. denote the rings or circular lines mentioned in the Theorem, and Y and X denote their centres, and the lines 1 *a* parallel to and equal to XY, the line of distance of the centres will continue equal and parallel to that line of distance in the positions 2 *c*, and 3 *e*, and 4 *g*, and in all other positions into which the point 1 can be brought, during the uniform, equal, and similarly-directed revolutions of the two circles.

Thirdly, if a wheel DDDD, (Fig. X. No. 1, 2, and 3,) B being its axis, which I shall here call the pitch-wheel, be constructed, (denoted by the black circle, Fig. IX.) having four or any other number of paddles *ab*, *ac*, *fe*, *hg*, parallel to each other, and capable of being turned or shifted in their position upon their respective axes 1, 2, 3, 4, and cranks equal in length to XY, be attached to another wheel or revolving piece, (denoted by the dotted circle, Fig. IX.) AAAA, which I call the connection-wheel or piece, it will be a necessary consequence that if one of those wheels be made to revolve, the other will also revolve in the same direction, and with the same velocity, and the paddles will continue parallel to each other.

In cases where the axle has a bearing on each side of the wheel, as in Fig. X. there is a circular piece C, which serves as an arbour for the connecting-wheel, by its smooth socket to revolve upon. C is by the construction, eccentric with regard to the pitch-wheel, and sufficiently large to allow the arbour B of the pitch-wheel to pass through it without interfering with the

motion of the connecting-wheel. But in such constructions of the machinery as do not require the arbour B for the pitch-wheel to pass through, instead of the piece C, may be substituted a simple pivot, or any other kind of centre to govern the circular motion of the connecting-circle.

For other applications of this mechanical principle, the reader is referred to the Repository of Arts and Manufactures, for the year 1814, where the specification is inserted.

## SECTION V.

78. Another method of propelling vessels, which occurred to me, is represented in Fig. XI. Like Mr. Linaker's plan (Art. 58.) it draws in the water at the bow and discharges it at the stern *; but instead of producing this effect by a pump, it is done by means of a horizontal wheel, somewhat on the principle of the fanners, or winnow-

* Mr. Watt informs me, that about 20 years ago, he tried a pump similar to Mr. Linaker's, to propel a vessel for Mr. Rumsey, but its effect in moving a boat was found very small. Mr. Watt, however, justly observed, that Mr. Rumsey applied the power to great disadvantage, because he forced the water through a very small pipe, which, of course, occasioned much friction; and that the pipe should have been as large as the bore of the pump barrel.

ing machine, which produces its effects by a centrifugal motion; but the wheel, in the winnowing machine, works vertically.

A A A A is the wheel placed in the middle of the vessel, a little below the waterline, and inclosed in a case communicating with the induction-pipe below, and with the discharging-pipe above. The wheel being in motion by its centrifugal force expels the water by the discharging-pipe at the stern, while water rushes in from the bow, to supply its place; and the vessel, by this means, receives a progressive motion.

*Observation.*

79. This method is simple, and possesses the advantage of occupying little space, and being applicable to vessels in rough water; but as the models which I made of it were on too small a scale to draw an accurate inference from the trials of them, I am unable to give a satisfactory account of what might be expected to be its effect were it executed on the large scale.

## SECTION VI.

80. A contrivance which has often been suggested, is, that of using a number of things resembling umbrellas, which would fold together when pushed forward, and expand when drawn backward in the water, and thereby propel the vessel; but however effectual, for a short time, such mechanism might be, it is obvious to every mechanic of experience, that there is little hope of rendering this or any other such folding and unfolding, or hinged machinery, sufficiently strong and durable in practice to answer the proposed end.

## SECTION VII.

81. In a former part of this Treatise, (Art. 1.) I mentioned a variety of projects for propelling vessels independently of the wind, which were made public previously to the invention of steam boats, and although I thought it there unnecessary to enter into their detail, it may not be inconsistent with the plan of this part of the Treatise to describe, in this and the following section, two of them, which, on account of their ingenuity, seem to merit notice.

In the "*Recueil de Machines approuvees par L'Academie Royale de Sciences, Tome* I." there is an account of revolving oars, invented by M. Du Quet.

These oars were simply four paddles fixed in an arbour, (see Fig. XII. No. 1, 2,) which worked over the side of the vessel. On the inner extremity of the arbour, a double crank was sustained by a small frame from the deck. These cranks were turned by a number of men, by means of a kind of moving frame; but upon this plan M. Du Quet afterwards made an ingenious alteration, with a view to remedy an inconvenience which arose from the oars in coming out of the water, dragging after them a sheet of water, which was a hinderance that would not occur, if the oar went out of the water with its edge. This alteration is thus described:

"The oars AB, CD, instead of being fixed on the arbour E, were made to turn in it during the revolution of that arbour. Each oar, as FGH, (see Fig. XII. No. 3, 4,) consisted of one piece; their surfaces were disposed in contrary directions; that is to say, while the one oar, F, presented

its flat side, the other, H, presented its edge. About the middle of each oar there was fixed a pin, IL, perpendicular to its surface; these pins were equally long on both sides. Around the port-hole, where the arbour of the oars passes, there was fixed two concentric semicircles, MNOPQR, firmly attached to the side of the vessel. The interval, OPQN, was filled with a piece of solid wood. This piece being fixed in the place which we have pointed out, where the oar revolves, following the arcs, H*h*, F*f*, the pin comprised in the void interval of the circles, MNQR, comes to encounter the side, NQ, the oar, F, turns itself necessarily upon its flat side to enter the water, and reciprocally the oar, H, turns on its edge to come out. This also occurs to the first, F, when it has made its half revolution; and as the filled up part, NQPO, only goes one quarter of the circle, we see that this change is not made untill after the oar has passed the vertical position, and has produced all the effect of which it is capable. By this construction, the inconvenience which attended this sort of oars was removed *."

* Recueil de Machines Approuvees, p. 186.

It appears, that a comparative trial of M. Du Quet's revolving perpendicular oars, with those in an ordinary galley, was made in the year 1693, at Marseilles, by order of Louis XIV *. The result was in favour of the galley having the machinery, and in 1702, the invention was approved in form by the Academy of Sciences.

## SECTION VIII.

82. The other project was brought forward by M. Martenot, about the year 1703, and in the *Recueil de Machines approuvees par L'Academie Royale de Sciences, Tome* II. p. 65. it is thus described:

"This oar is formed of a triangular prism, ABCDE, (see Fig. XIII. No. 1, 2, 3,) adapted to the stern of a vessel, V. The arbour, FGH, fixed in the centre of this prism, is prolonged to I, above the stern of the vessel. The point, F, is supported by a triangle of iron, FON, firmly attached to the side of the keel. The sides of this triangle ought to be elongated, and much spread out to leave the play necessary for the rudder, between the prism, and the vessel: the upper part of the same arbour is

* A previous trial was made in the year 1687.

supported by the irons, GH, which permit the prism to move horizontally, by means of the cross-head LM; at the extremities of which are ropes which serve to move it.

"This prism is a section of a cylinder, of which the side ABC is less than a semicircle. The cylinder from which this section is made, should have for the diameter of its base the greatest breadth of the vessel, and the height equal to the water-line; that is to say, if the vessel be twenty feet beam, and draw about 5 feet water, it should have a cylinder of 10 feet radius, and 5 feet of height; it follows, that each face, P, R, of the section, would have 50 feet of superficies."

By moving this section or single oar, by means of the cross-head LM, from right to left, and from left to right, M. Martenot supposed that the vessel should be propelled with the effect of many oars.

But the application of this oar to a ship, seemed attended with many difficulties; such as being subject to be carried away by the waves, impeding the effects of the rudder, &c.; nor does it appear that it ever was reduced to practice, nor was it approved of by the Academy of Sciences.

## PART III.

83. Having said so much respecting steam navigation on the Clyde, I come now to speak of what has been done on other rivers in the British islands.

### *The Forth.*

84. The vessel A, (see Art. 12.) in the year 1813, made a voyage through the Forth and Clyde canal, and thence, on the Forth, to Leith, and returned by the same route.

In the spring of 1814, the Stirling, a vessel of 56 feet keel, 15 feet beam, with an engine of 12 horses' power, began to ply between the towns of Stirling and Leith, where she still continues.

In the present year (1815) other two vessels have been added on the Forth.

1st, The Lady of the Lake, 65 feet keel, 16 feet 4 inches beam, having an engine of 20 horses' power. This vessel also plies between Stirling and Leith.

2d, The Morning Star, 80 feet keel, 16 feet beam, 26 horses' power, plies between Leith and Alloa.

The Lady of the Lake at present (August 1815) usually makes the voyage down the river in 5 hours, and up in 5½, a distance of 52 miles.

*The Tay.*

85. A vessel was put in motion on this river, in the year 1814, between Perth and Dundee, and none have been added on that station.

A steam vessel, built at Dundee, went thence to Hull, and, on her way, crossed the bar of Sunderland in very tempestuous weather.

*The Avon.*

86. In the year 1813, a steam boat was built at Bristol, and plied between that place and Bath. The same vessel, by inland navigation, went to the Thames for a short time, but was prevented by the Watermen's Company from taking passengers. For that reason, the proprietor returned the vessel to her former situation

in Somersetshire, where she continues. Another was some time ago building for the same situation.

*The Severn.*

87. A steam boat plies between Worcester and Gloucester.

*The Thames.*

88. In the winter of last year, a steam boat, as already mentioned, (see Art. 50,) went from the Clyde through the Forth and Clyde Canal, and thence to the Thames; and has all this season (1815) plied between London and the neighbourhood of Gravesend. It was also mentioned, that the steam boat E had gone from the Clyde, round the Land's End, to the Thames, and now plies between London and Margate.

Another boat, having the paddle-wheel on a new construction, and placed in the middle, was, some time ago, fitting up at the Surry canal dock. (August 1815.)

A small steam boat went over, this summer, from the Thames to Havre de Grace. She was purchased by Messrs. Andriel Perin & Co. of Paris, who have an exclusive privilege for the use of steam boats in France.

*The Yare.*

89. One or more steam boats ply on this river, from Yarmouth to Norwich.

*The Trent.*

90. A steam boat, which was built at Dundee, (see Art. 85.) has been, for a considerable time, plying between Hull and Gainsborough.

*The Tyne.*

91. A steam boat was set a-going on the Tyne in 1814, and there are now, I believe, three on that river.

*The Mersey.*

92. It was already mentioned that the steam boat B had gone from the Clyde to the Mersey, and now plies between Liverpool and Runcorn. An iron steam boat is now building, intended for the same station.

*Ireland.*

93. There is only one steam boat, that I have yet heard of, in Ireland. It began this summer (1815) to ply between Cork and the Cove.

## PART IV.

### NAVIGATION BY STEAM IN AMERICA.

94. The first steam boat in America was launched at New York, on the 3d of ~~Oc-~~ August ~~tober~~ 1807, and began to ply on the North River, between that city and Albany, a distance of about 150 miles. The builder of this boat is understood to have been Mr. Robert Fulton, a native of North America, who was some time in Great Britain, and well known as an engineer.

At New York, in the year 1814, two steam boats, and one cattle boat (of which kind of boats I shall afterward speak) plied on the ferry of North River, and the same on the ferry between that city and the State of New Jersey: some of them on the ferry are double-boats, having the paddle-wheel in the middle. Besides these, there were five which went up the river, one of them to Poughkeepsie, and the rest to Albany. The American steam boats are all of large dimensions, compared with any yet in Britain; and

some of them have four paddle-wheels; two near the bow, and two near the stern.

There are two vessels which ply on the river St. Laurence, in Canada, between Quebec and Montreal: at one place during the voyage, they have to ascend a considerable current.

*Steam Frigate.*

95. The Americans have been the first to apply a steam vessel to the purposes of war, and have built a steam frigate (to commemorate the inventer of steam navigation) called *Fulton the First* *. It is a double vessel, having the paddle-wheel in the middle, carrying 32 long 18-pounders, bomb proof, and five feet thick in the sides, in order the better to defend her from the shot of an enemy.

The American papers of July 1815, contain an account of an experiment for moving this ship of war by steam, which has been made at New York. The experiment is stated to have been successful. A New York paper thus describes what passed on the occasion:—

* Mr. Fulton died at New York, in 1815, in his 54th year.

"She proceeded majestically into the river, though a stiff breeze from the south blew directly a-head. She stemmed the current with perfect ease, as the tide ran a strong ebb. She sailed by the forts and saluted them with her 32-pound guns. Her speed was equal to the most sanguine expectation. The intention of the commissioners being solely to try her machinery, no use was made of her sails.

"It is now ascertained, by actual experiment, that this grand invention in war and the arts, will realise all the hopes of its warmest friends. Our government may be proud, that the trial has been made under their auspices. Our enemies may tremble at the tremendous power thus arrayed against them. Every harbour in the United States has now the means of protecting itself against stronger maritime forces. All the ports of the weaker European nations may henceforward secure themselves against the attacks of their foes, how formidable soever at sea.

"After navigating the bay, and receiving a visit from the officers of the French ship of war, lyeing at her anchors, the steam

frigate came to, near the Powlesshook Ferry, about two o'clock, without having experienced a single unpleasant occurrence *."

96. It appears from the newspapers †, that another "steam frigate has been launched at New York; length on deck, 300 feet; breadth, 200 feet; thickness of her sides, 13 feet of alternate oak plank and cork wood; carries 44 guns, four of which are 100-pounders; waist guns, 60-pounders; quarter-deck and forecastle guns, 42-pounders; and farther, to annoy an enemy attempting to board, can discharge 100 gallons of boiling water in a minute, and, by mechanism, brandishes three hundred cutlasses with the utmost regularity over her gunwales, works also an equal number of heavy iron pikes of great length, darting them from her sides with prodigious force, and withdrawing the same every quarter of a minute."

97. "In 1810, the building of steam boats was commenced at Pittsburgh, United States,

* Glasgow Chronicle, 8th August, 1815.

† See Edinburgh Evening Courant, 31st August, 1815.

by Mr. Rosevelt, in conjunction with Messrs. Fulton and Livingston of New York, by building the New Orleans, of 138 feet keel, and between 300 and 400 tons burden; after which, were built the Vesuvius, Enterprize, Etna, and Buffalo; besides which, the ——— lately launched, and one on the stocks, which will be launched in the ensuing summer."

## *PART V.*

### BOATS PROPELLED BY CATTLE.

98. Besides steam boats in North America, there are now boats propelled by means of cattle, which they call horse boats, or team boats. The proprietors use the latter term as having, as they suppose, a more attractive sound. These boats are propelled by the animals (from 8 to 13 horses or mules in each boat) drawing a gin, which, by wheel-work, communicates motion to paddle-wheels (similar to those of steam boats) in the middle of a double vessel.

At New York, in the summer of 1814, one of those team boats was plying on each of the ferries, (see Art. 94.) and two more were building for longer voyages.

99. *Description of an American Cattle Boat.*

Fig. XIV. No. 1, Plan.
Fig. XIV. No. 2, Elevation.
Fig. XIV. No. 3, Longitudinal section.
Fig. XIV. No. 4, Transverse section.

The boat is double, having the paddle-wheel placed in the middle; the horses or mules work in a gin on the deck, and, by means of toothed wheel-work, communicates motion to the paddle-wheel.

ABC, the horse course.

DE, large beveled-wheel, which drives the pinions GG.

H, H, spur-wheels attached to the pinions G, G, which work on studs, and communicate motion to the pinions I, I, and which are coupled to the axle of the paddle-wheel K.

## *PART VI.*

### INTRODUCTION.

100. As very loose and inaccurate notions relative to the forms of vessels, for the purposes of navigation, are known to prevail, not only among those who have not attended much to the subject, but even among shipwrights and seamen, I have attempted, in this part of the Treatise, to bring within a small compass what appeared useful in books, and which I thought would be beneficial to those whose time being otherwise fully occupied, have neither leisure, opportunity, nor inclination, to make such search themselves.

101. All the researches which have been made into the origin and progress of naval architecture, have but ill rewarded the labour and time bestowed in the pursuit. As an art, it can hardly be said to have existed among the ancient nations of Europe.

The probable fact is, that the floating body on which man first entrusted himself, was neither the result of imitation, of reflection, nor of skill; something that chance threw in his way, when prompted by necessity to cross a river or a strait; probably a floating tree, a hollow trunk, or a roll of bark; which, when the sap rises, is easily stripped off. That such cylindrical vessels were used at an early period, may be inferred from the almost universal use in which one or other is still met with among the savage islanders, in different parts of the globe. This has also been inferred, from the name of almost every kind of sailing vessel having a relation to something hollowed or scooped out; from the general term *vessel*, *(vas,)* down to the canoe, *(canna,)* a cane or hollow cylinder. The origin of the term *bark*, which, in Danish, Swedish, and English, is employed to express a ship, is, from this analogy, also obvious; of which the term *barge*, a little bark, is a diminutive. *Chaloupe*, *shallop*, or *sloop*, is from *chalumeau*, a hollow reed or cane. The idea is indeed extended to the appellatives *skiff*, *schip*, *ship*, whose deriva-

tion is from a Greek word signifying to dig out, to excavate; and *hull*, *hulk*, *hold*, conveys the same idea—something that is *hollow*, or that will contain or *hold*.

Almost all the terms and names employed in the equipment and management of a ship, are of northern origin; as *stern*, *starboard*, *oars*, *rudder*, &c. which shows that it was from our northern invaders that we derived the art of ship-building and navigation. In the east, the art appears to have been in the lowest state.

One nation of the east, however, of which the ancients scarcely knew the name, had, in all probability, made considerable progress in naval architecture. The ships of the Chinese, as described by Marco Polo, in the 13th century, were precisely what they now are, and what they probably were thirteen centuries before that period. They are now, and were then, such as, in size, shape, and construction, may be put on a level with the ships of Great Britain in the early part of the reign of Henry VIII.

It would be inconsistent with the plan of this Treatise to enter farther into the history of naval architecture than to state, that, ac-

cording to Mr. Seppings, "little or no advancement has been made within the last century in naval architecture, so far as relates to the disposition of materials which compose the fabric of a ship *." Mr. Seppings himself, however, with others in our own time, we hope have done, and are doing, much to remove this stigma †.

## SECTION I.

### *Of the Resistance of Fluids.*

102. In the theory of naval architecture the resistance of fluids is a subject of much importance. The impulse of the air, in sailing vessels, is the moving power; this must be modified to produce every motion we want, in the form and disposition of the sails; and it is the resistance of the water which must be overcome, that the ship may proceed on her course. Nor is it of less consequence, as connected with the propelling of vessels, by means of machinery acting against the water in which the vessel moves.

* See, on this subject, an able Paper in the Quarterly Review, Vol. XXIV. with which I have here made free.

† The new establishment of a *superior class of shipwright apprentices* promises much for the improvement of ship-building.

103. Sir Isaac Newton appears to have been the first who attempted to make the motions and actions of fluids the subject of mathematical discussion.

After exerting his great powers to form a theory, he was convinced that it was in vain to expect an accurate investigation of the motions of fluids, where millions of unseen particles combine their influence. He, therefore, cast about to find some particular case or problem, which would admit of an accurate investigation, by which many useful propositions might be determined for directing us in the application of those doctrines to the arts of life.

He figured to himself a hypothetical collection of matter, which possessed the characteristic property of fluidity, which the learned have termed the *quaquaversun* propagation of pressure, and the most perfect intermobility of parts, and which formed a physical (or natural) whole, or aggregate, whose parts were connected by mechanical forces, determined both in degree and direction, and such as rendered the determination of certain important circumstances of their motion, susceptible of precise investigation.

104. It must be acknowledged that the results of this theory very ill agree with practical experiments. But it presents such a beautiful specimen of geometry and calculus, that mathematicians have been fascinated by it to such a degree, that they have published systems so elegant and so extensively applicable, that one cannot help lamenting that the foundation is so unstable. But, with all its imperfections, this theory furnishes many propositions of immense practical use, they being the limits to which the real phenomena approximate; so that when the law by which the phenomena deviate from theory, is once determined by a well-chosen set of experiments, this hypothetical theory becomes almost as valuable as a true one. This theory of Newton continues to be the ground-work of all our practical knowledge of the motions of fluids. Its defects were all pointed out by its great author, who not only took the lead, but, with the exception of Daniel Bernoulli and D'Alembert, pointed out the path which others have taken.

105. We know by experience, that force must be applied in order to move a body

through a fluid, such as water, and the analogy of nature makes us imagine that there is a force opposing the motion, and that this force resides in the water, therefore, we give to this supposed force, the metaphorical term, *resistance.*

106. We also know that a fluid in motion will carry a solid body along with the stream, and that it requires force to keep it in its place; a similar analogy makes us suppose the fluid exerts force in the same manner in which an active being impels the body before him; therefore, we call this the *impulsion of a fluid.* And as our knowledge of nature informs us that the mutual action of bodies are in every case equal and opposite, and that the observed change of motion, is only an indication, characteristic, and measure, of the changing force, the forces are the same (whether we call them impulsions or resistances) when the relative motions are the same, and, therefore, depend entirely on these relative motions. The force, therefore, which is necessary for keeping a body immovable in a stream of water, flowing with a certain velocity, is

the same, or very nearly the same *, with what is required for moving this body with this velocity through stagnant water.

107. A body in motion appears to be resisted by a stagnant fluid, because it is a law of mechanical nature that force must be employed in order to put any body in motion. Now, the body cannot move forward without putting the contiguous fluid in motion, and force must be employed for producing

* I say very *nearly* the same; for, in practice, there is a small difference, which Professor Robison accounts for in the following manner: "The difference in the resistance of the same body, moving in a stream or current, and moving in still water, may be readily conceived when we consider, that, in the former case, the body sails on a sloping surface, not merely along with the stream, but down it, and will, therefore, go faster than the stream, because it is floating on an inclined plane; and if we examine by the laws of hydrostatics, we shall find, that, besides its own tendency to slide down this inclined plane, there is an odds of hydrostatical pressure, which pushes it downwards. It will, therefore, go faster than the stream. This acceleration depends on the difference of pressure at the two ends, and will be more remarkable as the body is larger, and especially as it is longer. This may be distinctly observed, and it may also be remarked, that when a number of bodies are thus floating down the stream, the largest and longest outstrip the rest. A log of wood floating down in this manner, may be seen to make its way very fast among the chips and saw-dust which float alongside of it.

"Now, if a body be supported against the action of a stream, and the impulse be measured by the force employed to support it, it is obvious that part of this force is employed to act against that tendency which the body has to outstrip the stream; but this does not appear when we move a body with the velocity of the stream, through still water, having a horizontal surface.

this motion. In like manner, a quiescent body is impelled by a stream of fluid, because the motion of the contiguous fluid is diminished by this solid obstacle. The resistance, therefore, or impulse no way differs from the ordinary communications of motion among solid bodies.

108. From the theory of resistance already spoken of, the following principles were deduced as the laws of resistance and impulse of fluids. They are inserted here, in order to show how far they agree with actual experiment, and in what respects they differ. These laws form certain great lines to guide our investigations; and, as has been already observed, when the law by which the phenomena deviate from them is known, they become almost as valuable as if drawn with perfect truth.

1. "The resistances, and (by the laws of motion) the impulsions of fluids on similar bodies are proportional to the surfaces of the solid bodies, to the densities of the fluids, and to the squares of the velocities, jointly. (See Art. 49.)

2d, "The direct impulse of a fluid on a plane surface, is to its oblique impulse on the same surface, as the square of the radius is to the square of the sine of the angle of incidence.

3d, "The direct impulse on any surface, is to the oblique impulse on the same surface, as the cube of radius to the solid which has the square of the angle of incidence for its base, and the sine of obliquity for its height.

4th, "The direct impulse of a stream of fluid, whose breadth is given, is to its oblique effective impulse in the direction of the stream, as the square of radius to the square of the sine of the angle of incidence."

109. For other laws of the resistance of fluids, I beg to refer to Professor Robison *. It seems to me unnecessary here to enter farther into them than to give the following inductions.

1st, "That the impulse on a cylinder or half cylinder is two-thirds of the direct impulse on its transverse plane through the axis."

* Encyclopædia Britannica, Art. Resistance.

2d, "The impulse on a sphere is one-half the direct impulse on its great circle, or on the base of a circle of equal diameter."

110. From the principles which Sir Isaac Newton discovered, he theoretically determined the form of a solid, which of all others of the same length and base should have the least resistance. In the same inductive manner, it may be proved that,

3d, "The direct impulse or resistance of an unelastic fluid on any plane surface, is equal to the weight of a column of the fluid having the surface of its base, and twice the fall for acquiring the velocity of the motion for its height: and if the fluid is considered as elastic, the impulse or resistance is twice as great*".

111. It now remains to compare this theory with experiment. Many experiments were made by Sir Isaac Newton and subsequent writers. His were chiefly made by the oscillations of pendulums in water, and the descent of balls both in water and

* See Newton's Principia, B. II. Prop. 35 and 38.

air. The most complete set of experiments on the resistance of water, previous to those made by the Society for the Improvement of Naval Architecture, are those which were made in France, at the public expense, by a committee of the Academy of Sciences. Chev. de Buat, in his *Hydraulique*, has also published some most curious and valuable experiments.

112. 1st, It is very consonant to experiment, that the resistances are proportional to the squares of the velocities. When the velocities of water do not exceed a few feet per second, no sensible deviation is observed. In very small velocities, the resistance is sensibly greater than in this proportion, and this excess is plainly owing to the viscidity or imperfect fluidity of water.

In the experiments made with bodies floating on the surface of water, there is an addition to the resistance, arising from the *inertia* of the water. The water heaps up a little on the anterior surface of the floating body, and is depressed behind it. Hence arises a hydrostatical pressure, acting in concert with the true resistance.

These circumstances cause the resistance to increase faster than the squares of the velocities: but, independently of this circumstance, there is an additional resistance arising from the tendency to rarefaction behind a very swift body; because the pressure of the surrounding fluid can only make the fluid fill the space left with a determinate velocity. This tendency to rarefaction has been termed, *non*-pressure or *minus*-pressure.

113. As an illustration, it may be added, that it has frequently been observed from the poop of a second rate man-of-war, when she was sailing 11 miles an-hour, which is a velocity of 16 feet per second nearly, not only that the back of the rudder was naked for about two feet below the load-water line, but also, that the trough or wake made by the ship was filled up with water, which was broken, and foaming to a considerable depth, and to a considerable distance behind the vessel. While this broken or dead water is observed, there must be a partial diminution of pressure, which will operate as an additional resistance.

114. But the deeper a moving body is immersed in water, the less will be the hinderance from *non*-pressure; for the greater pressure of the surrounding water will cause it more rapidly to come in behind.

115. The effect of deep immersion is generally misconceived by those not accustomed to mathematical researches. Indeed, it is a commonly received opinion, that the resistance increases in proportion to the depth; and a writer * on naval architecture has fallen into the same error.

116. "It is only in great velocities," observes Professor Robison, "where the depth has any material influence; neither is the influence by far so considerable as we should, at first, suppose. For, in estimating the effect of immersion, which has a relation to the difference of pressure, we must always take in the pressure of the atmosphere; and thus the pressure at 33 feet deep is not 33 times the pressure at one foot deep, but only double, or twice as great."

* Mr. Gordon, in his Principles of Naval Architecture.

With these corrections for *non*-pressure, &c. then, it may be asserted, that theory and experiment agree in this respect, that the resistance is in the duplicate ratio (or as the square) of the velocity.

2d, It appears, from a comparison of all the experiments, that the impulses and resistances are very nearly in the proportion of the surfaces. They appear, however, to increase somewhat faster than the surfaces. The Chevalier Borda found that the resistance, with the same velocity, to a surface of

$$\left.\begin{array}{r}9\\16\\36\\81\end{array}\right\}\text{ was }\left\{\begin{array}{r}9\\17{,}535\\42{,}750\\104{,}737\end{array}\right\}\text{ instead of }\left\{\begin{array}{r}9\\16\\36\\81\end{array}\right.$$

The deviation in these experiments from the theory, increases with the surface, and is probably much greater in the extensive surfaces of the sails of ships and windmills, and the hulls of ships.

3d, The resistances do by no means vary in the duplicate ratio of the angles of incidence.

This is an interesting circumstance, as on it depends the whole theory of the construction and working of ships. I shall

here insert the experiments made on this subject by the French Academy.

117. Fifteen boxes, or vessels, were constructed, which were two feet wide, and two feet deep, and four feet long. One of them was a parallelopiped of these dimensions; the others had prows of a wedge form, the angle A C B (Fig. XIV. No. 5.) varying by $12^{\circ}$ from $12^{\circ}$ to $180^{\circ}$; so that the angle of incidence increased by $6^{\circ}$, from one to another. These boxes were dragged across a very large basin of smooth water (in which they were immersed two feet) by means of a line passing over a wheel connected with a cylinder, from which the actuating weight was suspended. The motion became perfectly uniform after a very little way; and the time of passing over 96 French feet, with this uniform motion, was very carefully noted. The resistance was measured by the weight employed, after deducting a certain quantity (properly estimated) for friction, and for the accumulation of the water against the anterior surface.

The results of the many experiments are given in the following Table:

TABLE.

| *Angle of the Head End.* | *Resistance according to Theory.* | *Resistance according to Experiment.* | *Difference between Theory & Experiment.* |
|---|---|---|---|
| 180° | 10000 | 10000 | 0 |
| 168 | 9890 | 9893 | +3 |
| 156 | 9568 | 9578 | +10 |
| 144 | 9045 | 9084 | +39 |
| 132 | 8346 | 8446 | +100 |
| 120 | 7500 | 7710 | +210 |
| 108 | 6545 | 6925 | +380 |
| 96 | 5523 | 6148 | +625 |
| 84 | 4478 | 5433 | +955 |
| 72 | 3455 | 4800 | +1345 |
| 60 | 2500 | 4404 | +1904 |
| 48 | 1654 | 4240 | +2586 |
| 36 | 955 | 4142 | +3187 |
| 24 | 432 | 4063 | +3631 |
| 12 | 109 | 3999 | +3890 |

The resistance to one square foot, French measure, moving with a velocity of 2.56 feet per second, was very nearly 7.625 pounds French. Reducing these to English measures, we have the surface equal to 1.1363 feet, the velocity of the motion equal to 2.7263 feet per second, and the resistance equal to 8.234 pounds, avoirdupois.

From these experiments, we may perceive that the effects of the obliquity of incidence deviate enormously from the theory of the mathematicians; and that this deviation increases rapidly, as the acute-

ness of the prow, or head-end, increases. In the prow of 60 degrees, the deviation is nearly equal to the whole resistance, pointed out by the theory; and, in the prow of 12 degrees, it is nearly 40 times greater than the theoretical resistance.

These experiments are very conformable to those of Mr. Robins and Chevalier Borda *; and it has been found in all cases of oblique plane surfaces, that the resistances were greater than those which were assigned by theory. The theoretical law agrees tolerably with observation, in large angles of incidence; that is, in incidences not differing very far from the perpendicular; but in more acute prows, the resistances are more nearly proportional to the sines of incidence than to their squares.

118. As the very nature of naval architecture seems to require curvilineal forms, in order to give the necessary strength, it seemed of importance to examine more particularly the deviations of the resistances of such prows from the resistances assigned by the theory.

* See Encyclopædia Britannica, Art. Resistance.

The academicians, therefore, made vessels with head-ends of a cylindrical shape; one of these was a half cylinder, and the other was one-third of a cylinder, both having the same breadth, *viz.* two feet; the same depth, also two feet; and the same length, four feet. The resistance of the half cylinder, was to the resistance of the perpendicular prow in the proportion of 13 to 25, instead of being as 13 to 19.5. The Chevalier Borda found nearly the same *ratio* of the resistances of the half cylinder, and its diametrical plane, when moved in air. He also compared the resistances of two prisms or wedges of the same height and breadth. The first had its sides plane, inclined to the base, in angles of 60 degrees; the second had its sides portions of cylinders, of which the planes were the chords, that is, their sections were arches of circles of 60 degrees. Their resistances were as 133 to 100, instead of being as 133 to 220, as required by the theory; and, as the resistance of the first was greater in proportion to that of the base than the theory allows, the resistance of the last was less.

119. Mr. Robins found the resistance of a sphere moving in air, to be to the resistance of its great circle, as 1 to 2.27; whereas the mathematical theory requires them to be as 1 to 2. Borda found the resistance of the sphere moving in water, to be to that of its great circle as 1000 to 2508. He also found the resistance of air to the sphere, was to its resistance to its great circle as 1 to 2.45.

120. It appears on the whole, that the theory gives the resistance of oblique plane surfaces too small, and that of curved surfaces too great; and that it is quite unfit for ascertaining the modifications of resistance arising from the figure of the body. The most prominent part of the prow changes the action of the fluid on the succeeding parts, rendering it totally different from what it would be, were that part detached from the rest, and exposed to the stream with the same obliquity.

These experiments of the French Academy are of importance, because they give us the impulses on plane surfaces with every obliquity. By referring to them, we may

perceive the proper obliquity in many cases, and can tell what is the proper angle of the sail for producing the greatest impulse in the direction of the ship's course, &c.

121. It has been observed by Professor Robison, that "the experiments of the French Academy above described, are of great value, and may always be appealed to; but that there are circumstances in them which render them more complicated than is proper for a general theory; and which, therefore, limit the conclusions that might otherwise be drawn from them. The bodies were floating on the surface; and this circumstance necessarily produced the *plus* and *minus* pressures, or what the academicians called the *remou*, or accumulation on the fore part of the body and depression behind it. This resistance was measured with great difficulty and uncertainty, as was likewise the effect of adhesion or friction of the water, which must also have been very considerable and very different in the different cases. It is necessary to consider these particulars as making part of the resistance in the most important practical cases, *viz.*

the motion of ships; for here we see that its effect is very great; as it is well known that the speed, even of a coppered ship, is greatly increased by greasing her bottom, and thereby reducing the effect of this adhesion, &c.: and it is, therefore, to be concluded, that the form of these experiments was not so well suited as could have been wished, for the complete determination of the causes of resistance." This desideratum has, however, been much more completely attained by the experiments, of which I shall present an abstract from the "Report of the Society instituted at London for the Improvement of Naval Architecture." But it may be proper, previously, to take a short view of the experiments made by the Chevalier de Buat, already mentioned.

## SECTION II.

*Experiments illustrative of the Motions of resisted Fluids, by the Chevalier de Buat.*

122. It appears, from experiments made by the Chevalier de Buat, that the resistances of different surfaces, equally immersed, is greater than in the proportion of the breadth. That is to say, a broader

plane, when it is not completely immersed, will be resisted more than a narrower one, equally immersed, by a resistance greater in proportion than the difference of breadth. For example: we shall suppose two planes, A and B, of which the lesser (A) shall be one foot square, and the larger (B) two feet broad by one foot deep. When these are equally immersed, the resistance of B will be greater in proportion to its surface, than the resistance of A in proportion to its surface. For, it is evident, that there will be an accumulation against both; but the elevation against B will be proportionally greater than that against A, because the lateral escape of the water from the greater surface, is more difficult than that from the lesser, as will appear from the following experiments.

The instrument made use of in these experiments, was that represented in Fig. XV. No. 1. It consisted of a square brass plate, ABGF, pierced with a great number of holes, and fixed in front of a shallow box, represented edgewise in Fig. XV. No. 2. The back of this box was pierced with a hole C, in which was inserted the tube of

glass CDE, bent square at D. This instrument was exposed to a stream of water, which beat on the brass plate. The water having filled the box through the holes, stood at an equal height in the glass tube, when the surrounding fluid was stagnant; but when it was in motion, it always stood in the tube above the level of the smooth water without, and thus indicated the pressure occasioned by the action of the stream.

When the instrument was not wholly immersed, there was always a considerable accumulation against the front of the box, and a depression behind it. The water before it was not stagnant; indeed, it could not be so, for, as M. Buat observes, it consists of the water which was escaping on all sides; and, therefore, upwards from the middle of the stream, which meets the plate perpendicularly in C, considerably under the surface. It escapes upwards; and, if the body were sufficiently immersed, it would escape in this direction almost as easily as laterally. But, in the present circumstances, it heaps up, till the elevation occasions it to fall off sidewise as fast as it is renewed. When

the instrument was immersed more than its semi-diameter under the surface, the water still rose above the level, and there was a great depression immediately behind this elevation. In consequence of this difficulty of escaping upwards, the water flows off laterally; and, if the horizontal dimensions of the surface be great, this lateral efflux becomes more difficult, and requires a greater accumulation. From this it happens that the resistance of broad surfaces, equally immersed, is greater than in the proportion of the breadth.

123. Thus, a plane of two feet wide and one foot deep, when it is not completely immersed, will be more resisted than a plane two feet deep and one foot wide; for there will be an accumulation against both: and even if these were equal in height, the additional surface will be greatest in the widest body, and the elevation will be greater, because the lateral escape is more difficult.

124. This completely proves the error of Mr. Gordon, and others, formerly alluded

to, (Art. 115.) with regard to deep immersion; and hence the same area of displacement in the midship frame, will have less resistance when deep than when wide, even supposing for a moment that no advantage were gained on the narrow vessel by water lines better adapted to divide the fluid *. And we may also here infer the advantage to be derived from having the paddle-wheels of a steam boat rather wide and shallow than narrow and deep, in order to find the best resisting surface.

125. It was found, that the pressure was much greater on the centre than towards the border; and, in general, that the height of the water in the tube D E was more than four-thirds, or one and one-third, of the height necessary for producing the velocity when only the central hole was open. When various holes were opened, at different distances from the centre, the height of the water in D E continually diminished, the nearer the hole was to the border. At a certain distance from the border, the water at E was level with the surrounding water, so

* The question of Stability will be considered in another place.

that no pressure was exerted on that hole. But the most unexpected and remarkable circumstance was, that, in great velocities, the holes at the very border, and even to a small distance from it, not only *sustained no pressure, but even gave out water;* for the water in the tube was *lower* than the surrounding water. M. Buat calls this a non-pressure. In a case in which the velocity of the stream was three feet, and the pressure on the central hole caused the water in the vertical tube to stand thirty-three *lines*, or twelfths of an inch, above the level of the surrounding smooth water, the action on a hole at the lower corner of the square caused it to stand twelve *lines* lower than the surrounding water. The intermediate holes gave every variation of pressure; and the diminution was more rapid the nearer the holes were to the edge; but the law of diminution could not be observed.

This was a new and unexpected circumstance in the action of fluids; yet it will be found consistent with the genuine principles of hydraulics: for a consideration of the subject will show, that if the middle alone were struck with a considerable ve-

locity, the water might even rebound, as is frequently observed. This actual rebounding is here prevented by the surrounding water, which is moving with the same velocity: but the pressure may be almost annihilated by the tendency to rebound of the inner filaments. Part (and perhaps a considerable part) of this apparent non-pressure is certainly produced by the tenacity of the water, which takes off with it the water lyeing in the hole. At any rate, this is an important fact, and gives great value to M. Buat's experiments.

126. From the experiments, it also appeared, that, with respect to the resistance, it is of no less consequence to attend to the form of the hinder part of a ship than to that of the prow. This truth seems to have been established by the experience of all nations. Nevertheless, M. Buat particularly directed his experiments to ascertain this point, and with success; for they plainly show the great importance of due consideration as to the action of the fluid on the after part of the body.

It is clear, from what has been before advanced, that the whole impulse or resistance

which must be withstood or overcome by the external force, is the sum of the active pressure on the fore part, of the non-pressure on the hinder part, and the effect of adhesion; or in other words, the sum of the plus and minus pressures and of friction. The experiments of M. Buat, showed that this does not depend solely on the form of the head, but also on the length of the body. It appeared by some of the experiments, that the non-pressure on the hinder part was prodigiously diminished (reduced to one-fourth) by making the length of the body triple that of the breadth. And hence it appears, that merely lengthening a ship, without making any change in the form either of the head-end or stern-end, will greatly diminish the resistance to the motion through the water. This increase of length may be made by continuing the form of the midship frame in several timbers along the keel, by which the capacity of the ship, and power of carrying sail, will be greatly increased, and other qualities improved, while the speed of the vessel is at the same time augmented *.

* See Encyclopædia Britannica, article Resistance, and Steel's Elements and Practice of Naval Architecture.

## SECTION III.

*Experiments made under the direction of the Society instituted at London for the Improvement of Naval Architecture.*

127. The Society for the Improvement of Naval Architecture, having directed that experiments should be made "To ascertain the Laws respecting Bodies moving through Water with different Velocities;" there were made, in consequence thereof, during the years 1793, –4, –5, –6, –7, and –8, several thousand experiments for this important purpose, by a more accurate apparatus than had ever before been used for experiments of this nature.

The results of the most important part of these experiments were published by, and at the expense of, the Society, in the year 1799, a short time before its much-to-be-regretted dissolution; and, from the report then published, the following abstract has been made. "The experiments will be found both curious and instructive. They explain many things which were before either not at all, or but very im-

perfectly understood, and they ascertain new principles; but, what is most valuable, they clearly prove, that experiments can now be made, by means of proper models, so as to ascertain the comparative advantages, or disadvantages arising from the form, either of the head-end, or of the midship body, or of the stern-end, of all kinds of navigable vessels."

In explanation of the Table, and of the figures comprehended under No. XVI, containing the figures of the different bodies, it is to be understood, that the bodies from figure 1 to figure 15, inclusive, are those by which experiments were made in the year 1798: figure 17 to 25, those of the year 1797: and figure 26 to 34, those of 1796. The experiments of the preceding years, unfortunately for science, have never been published.

It is also to be understood, that the column of velocity per second, as given in the Table, is that obtained by the motive weight of 60 lbs, and the different resistances and pressures taken when the respective bodies moved with a velocity equal to five nautical miles an-hour.

It is likewise to be observed, that the first letter of the respective references to the different bodies, denotes the head or foremost end of the body, as drawn through the water for experiment. For example, in describing the properties of the body A P i, A signifies the head or foremost end; and, in like manner, describing those of the body i P A, which is the same figure reversed, i denotes the head or foremost end, when the body is moving in a contrary direction.

The quantity of surface and friction of water, shown in the Table, is the surface and friction of the bottom and sides only; excepting those figures marked *; which, of course, show the total surface and friction. The former have been taken as showing more exactly the effect of friction on the different bodies considered as ships, &c.

# TABLE, SHOWING THE RESULTS OF EXPERIMENTS

MADE UNDER THE DIRECTION OF THE

## *Society for the Improvement of Naval Architecture.*

THE column of capacity shows the comparative stability of the different bodies: the velocity per second is with a motive weight of 60 lb.: the total resistance is equal to the weight, giving a velocity at the rate of five miles an-hour: the friction is that on the bottom and sides only: the resistance as a ship, and the pressures correspond, of course, with the foregoing velocities.

| | | *Capacity or Weight.* | *Velocity per Second. Wgt.60 lbs* | *Total Resistance.* | FRICTION OF WATER. | | *Resistance as a Ship.* | *Sum of Plus and Minus Pressures.* | *Minus Pressure only.* | *Plus Pressure only.* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Surface.* | *Friction.* | | | | |
| | | *lbs. dec.* | *ft. dec.* | *lbs. dec.* | *ft. dec.* | *lbs. dec.* | *lbs. dec.* | *lbs. dec.* | *lbs. dec.* | *lbs. dec.* |
| Conducting Body and Bar, - | (Fig. 1.) | ......... | 9.264 | 48.69 | | | | | | |
| Long Friction Plank, - - - - | (Fig. 2.) | ......... | 7.419 | 30.329 | 50.0 | 30.329 | | | | |
| Short Friction Plank, - - | (Fig. 3.) | ......... | 7.906 | 20.731 | 4.0 | 20.731 | | | | |
| Body, A o, - - - - - | (Fig. 4.) | 294.37 | 8.087 | 17.43 | 21.71 | 4.53 | 16.45 | 11.92 | 0.0 | 11.92 |
| Body, A a, - - - - - | (Fig. 5.) | 247.50 | 8.104 | 17.14 | 17.96 | 3.75 | 16.31 | 12.56 | 0.64 | 11.92 |
| Body, A b, - - - - - | (Fig. 6.) | 266.25 | 8.109 | 17.9 | 18.28 | 3.81 | 16.20 | 12.39 | 0.47 | 11.92 |
| Body, A c, - - - - - | (Fig. 7.) | 300.0 | 7.971 | 19.51 | 18.85 | 3.93 | 18.51 | 14.58 | 2.66 | 11.92 |
| Body, A d, - - - - - | (Fig. 8.) | 215.63 | 8.002 | 18.93 | 15.45 | 3.22 | 18.21 | 14.99 | 3.07 | 11.92 |
| Body, A e, - - - - - | (Fig. 9.) | 199.37 | 7.889 | 21.12 | 14.19 | 2.96 | 20.45 | 17.49 | 5.57 | 11.92 |
| Body, A f, - - - - - | (Fig. 10.) | 181.87 | 7.468 | 29.95 | 12.91 | 2.69 | 29.34 | 26.65 | 14.73 | 11.92 |
| Body, A g, - - - - - | (Fig. 11.) | 193.13 | 7.662 | 25.38 | 13.19 | 2.75 | 24.74 | 21.99 | 10.07 | 11.92 |
| Body, A h, - - - - - | (Fig. 12.) | 179.37 | 7.837 | 22.8 | 12.44 | 2.60 | 21.48 | 18.88 | 6.96 | 11.92 |
| Body, A i, - - - - - | (Fig. 13.) | 155.0 | 7.631 | 26.25 | 10.48 | 2.19 | 25.73 | 23.54 | 11.62 | 11.92 |
| Body, b A, - - - - - | (Fig. 6.) | 266.25 | 8.164 | 16.12 | 18.28 | 3.81 | 15.23 | 11.42 | 0.64 | 10.78 |
| Body, c A, - - - - - | (Fig. 7.) | 300.0 | 8.048 | 18.12 | 18.85 | 3.93 | 17.12 | 13.19 | 0.64 | 12.55 |
| Body, d A, - - - - - | (Fig. 8.) | 215.63 | 8.038 | 18.33 | 15.45 | 3.22 | 17.61 | 14.39 | 0.64 | 13.75 |
| Body, e A, - - - - - | (Fig. 9.) | 199.37 | 7.916 | 20.58 | 14.19 | 2.96 | 19.91 | 16.95 | 0.64 | 16.31 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Body, f A, | (Fig. 10.) | 181.87 | 7.736 | 24.10 | 12.91 | 2.69 | 23.49 | 20.80 | 0.64 | 20.16 |
| Body, g A, | (Fig. 11.) | 193.13 | 8.122 | 16.87 | 13.19 | 2.75 | 16.23 | 13.48 | 0.64 | 12.84 |
| Body, h A, | (Fig. 12.) | 179.37 | 7.983 | 19.37 | 12.44 | 2.60 | 18.77 | 16.17 | 0.64 | 15.53 |
| Body, i A, | (Fig. 13.) | 155.0 | 6.326 | 61.99 | 10.48 | 2.19 | 61.47 | 59.28 | 0.64 | 58.64 |
| Body, H o, | (Fig. 14.) | 226.25 | 7.960 | 19.78 | 16.19 | 3.38 | 19.02 | 15.64 | 0.00 | 15.64 |
| Body, I o, | (Fig. 15.) | 201.87 | 6.324 | 62.02 | 14.23 | 2.97 | 61.35 | 58.38 | 0.00 | 58.38 |
| Conducting Body and Bar, | (Fig. 16.) | ......... | 9.613 | 48.06 | | | | | | |
| Body, M N, | (Fig. 17.) | ......... | 7.514 | 26.13 | 8.96* | 1.87 | | | | |
| ——— Reversed, | | ......... | 5.768 | 75.95 | | | | | | |
| Body, R—A Cube, | (Fig. 18.) | ......... | 5.683 | 79.34 | 4.0* | 0.83 | | | | |
| Square Iron Plane, | (Fig. 19.) | ......... | 5.634 | 80.76 | | | | | | |
| Round Iron Plane, | (Fig. 20.) | ......... | 5.650 | 80.64 | | | | | | |
| Cylinder, | (Fig. 21.) | ......... | 5.795 | 74.69 | 4.0* | 0.83 | | | | |
| Cylinder and Semi-Globe, | (Fig. 22.) | ......... | 6.057 | 56.04 | 6.0* | 1.25 | | | | |
| ——— Reversed, | (Fig. 23.) | ......... | 7.738 | 22.28 | | | | | | |
| ——— with Semi-Globe on each end, | (Fig. 24.) | ......... | 7.977 | 18.53 | 8.0* | 1.67 | | | | |
| Globe or Sphere, | (Fig. 25.) | ......... | 7.578 | 25.24 | 4.0* | 0.83 | | | | |
| Conducting Body and Bars, | (Fig. 26.) | ......... | 9.992 | 44.20 | | | | | | |
| Long Friction Plank, | (Fig. 27.) | ......... | 7.773 | 26.02 | | | | | | |
| Short Friction Plank, | (Fig. 28.) | ......... | 8.548 | 14.70 | | | | | | |
| Body, A P a, or a P A, | (Fig. 29.) | 810.10 | 7.751 | 26.41 | 44.96 | 10.18 | 23.48 | 13.30 | 1.38 | 11.92 |
| Body, A p e, | (Fig. 30.) | 761.87 | 7.433 | 32.19 | 41.19 | 9.33 | 29.43 | 20.10 | 8.18 | 11.92 |
| Body, A [illegible]k, | (Fig. 31.) | 805.62 | 7.467 | 31.64 | 43.31 | 9.81 | 28.40 | 18.59 | 6.67 | 11.92 |
| Body, A P l, | (Fig. 32.) | 833.12 | 7.490 | 31.06 | 44.21 | 10.01 | 27.72 | 17.71 | 5.79 | 11.92 |
| Body, A P i, | (Fig. 33.) | ......... | 7.252 | 35.97 | 37.48 | 8.49 | 33.37 | 24.88 | 12.96 | 11.92 |
| Body, e P A, | (Fig. 30.) | 761.87 | 7.494 | 31.02 | 41.19 | 9.33 | 28.26 | 18.93 | 1.38 | 17.55 |
| Body, k P A, | (Fig. 31.) | 805.62 | 7.513 | 30.74 | 43.31 | 9.81 | 27.50 | 17.69 | 1.38 | 16.31 |
| Body, l P A, | (Fig. 32.) | 833.12 | 7.544 | 30.13 | 44.21 | 10.01 | 26.79 | 16.78 | 1.38 | 15.40 |
| Body, i P A, | (Fig. 33.) | ......... | 6.054 | 70.28 | 37.48 | 8.49 | 67.68 | 59.19 | 1.38 | 57.81 |
| Body, I P i, or i P I, | (Fig. 34.) | ......... | 5.830 | 79.16 | 30.0 | 6.79 | | | | |

O

*Preliminary Observations on the Experiments.*

128. For the purpose of ascertaining the effect of resistance arising from the friction of the water, two bodies were procured, called the *long friction plank*, and the *short friction plank;* these were of the same degree of smoothness, and also of the same breadth and thickness, and of the same form in every respect, except in length. Other bodies were also provided, some with a similar middle part and head end, but with differently-formed stern ends, for the purpose of ascertaining the effect of the stern resistance, and the *minus pressure;* and some with a similar middle part and stern end, but with differently-formed head ends, for ascertaining the effect of the head resistance and the *plus pressure.* All these bodies, planed smooth and painted white, were of the form and dimensions represented in the engraving; and, when used for experiment, were respectively immersed, by means of the conductor and its bar or bars, to the medium depth of six feet under the surface of the water; and, when so immersed, the conductor swum with its top, or horizontal upper surface, exactly one inch above the upper surface of the water.

*On the Resistance sustained by the different Bodies when considered as Navigable Vessels, &c.*

129. The bodies made use of for the different experiments, were severally immersed to the medium depth of six feet, as before mentioned, by means of the bar, or bars, affixed to the conductor. Consequently, in order to make comparisons with these bodies, considering them as ships, or navigable vessels, it was necessary to deduct the friction against the top surface from the total resistance. Such deductions were accordingly made, and the motive powers requisite to overcome the resistance of the bottom and sides only, as navigable vessels, were thereby ascertained.

In the experiments of the year 1798, the bodies A o, A a, &c. to A i, (Figures 4 to 13,) were constructed for the purpose of ascertaining the advantages or disadvantages arising from their differently-formed stern ends. Now, by inspecting the resistance of the bodies A o (Fig. 4) and A a, Fig. 5, (as ships,) as shown in the preceding Table, it will be seen, that the resistance of the

body A a, is a little less than the resistance of the body A o; and also, that the resistance of the body A h, (Fig. 12,) reversed as h A, is a little less than the resistance of the body H o (Fig. 14); which remarkable circumstance arises in each case from the stern end o, having a greater surface for friction than the stern end a. Whence it is evident, that the resistance arising from the friction against the stern end o, is greater than the friction and minus pressure, together of the stern end a.

Another remarkable circumstance, is, that the resistance of the body A b, Fig. 6, (as a ship) was found to be a little less in the velocities, from five miles per hour downwards, than the resistance of A a; but in the higher velocities, the body A a has the least resistance.

| | *1 mile* | *2miles* | *3miles* | *4 miles* | *5 miles* | *6 miles* | *7 miles* | *8 miles* |
|---|---|---|---|---|---|---|---|---|
| A a's Resistance | 0.66 | 2.70 | 6.03 | 10.60 | 16.31 | 25.15 | 31.02 | 39.88 |
| A b's Resistance | 0.62 | 2.58 | 5.85 | 10.40 | 16.20 | 25.21 | 31.38 | 40.69 |

This crossing is occasioned by the law of the stern resistance of the stern end b, increasing in a greater *ratio* than the stern resistance of the stern end a; and which probably arises from the angular part of the

stern end b, (that is, from s to b,) being more obtuse than that of the stern end a.

And, with respect to the bodies A c, A d, &c. to A i, it will be seen, that they have all greater resistances than either of the aforesaid bodies A o, A a, or A b; which are disadvantages that evidently arise out of the form of the stern end of the said bodies respectively; and of which the stern end f, of the body A f, (Fig. 10,) has the greatest disadvantage, or is the worst stern end of all.

The bodies A a, A b, A c, &c. to A i, (Fig. 5 to 13,) reversed, were made use of for the purpose of ascertaining the advantages or disadvantages arising from their several differently-formed head ends; and those different advantages or disadvantages will be seen by an inspection of the Table.

In the investigation of this subject, that is, considering the different bodies as representing ships, it must be noticed, that they have different magnitudes, and consequently, different degrees of stability, or stiffness to carry sail; and also, that the relation which the resistance bears to the capacity, or relation which the resistance bears to the *vis insita* force, or power of

going forward, and the momentum, will be different in each body.

Taking the subject in this point of view, it of course becomes necessary to ascertain the relation which the resistance bears to the capacity, and also the comparative degrees of stability of the respective bodies; whence we shall be able to draw conclusions applicable to practice.

And, as the bodies are of the same form and dimensions in their midship section, and only differ in length, and in the form of their head ends and stern ends; therefore, their comparative stability will be nearly in proportion to the capacities of the different bodies respectively. Whence it is readily conceived, that the comparative power, or quantity of sail, which the different bodies are capable of sustaining, will also be nearly in proportion to their respective capacities.

And the capacities, when considered as ships, or their weight as a column of water, are found to be as follow:

| | | | |
|---|---|---|---|
| *lb. dec.* | *lb. dec.* | *lb. dec.* | *lb. dec.* |
| A o=294.37 | A c=300.00 | A f=181.87 | A i=155.00 |
| A a=247.50 | A d=215.63 | A g=193.13 | H o=226.25 |
| A b=266.25 | A e=199.37 | A h=179.37 | I o=201.87 |

Then, by taking the resistances, say at the velocity of five miles an-hour, as shown in the foregoing Table, and placing them as numerators; and also by placing the capacities, or weights, as above, under their correspondent resistances as denominators; the numbers so placed, will represent the relation which the resistance bears to the capacity, and also the relation which the resistance bears to the *vis insita* force, or power of going forward, (or to the momentum,) all which relations are as follow:

| | *lb. dec.* | | *lb. dec.* | | *lb. dec.* | | *lb. dec.* |
|---|---|---|---|---|---|---|---|
| A o | Res. = 16.45 / Cap. = 294.37 | c A | Res. = 17.12 / Cap. = 300.00 | f A | Res. = 23.49 / Cap. = 181.87 | i A | Res. = 61.47 / Cap. = 155.00 |
| A a | Res. = 16.31 / Cap. = 247.50 | d A | Res. = 17.61 / Cap. = 215.63 | g A | Res. = 16.23 / Cap. = 193.13 | H o | Res. = 19.02 / Cap. = 226.25 |
| b A | Res. = 15.23 / Cap. = 266.25 | e A | Res. = 19.91 / Cap. = 199.37 | h A | Res. = 18.77 / Cap. = 179.37 | I o | Res. = 61.35 / Cap. = 201.87 |

For the sake of comparing the above numbers more readily, they have been considered as fractions, and reduced to their lowest terms, whence the relation which the resistance bears to the capacity, or the capacity to the resistance, &c. will be as follows:

| | A o | A a | b A | c A | d A | e A | f A | g A |
|---|---|---|---|---|---|---|---|---|
| Resistance, | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Capacity, | 17.895 | 15.175 | 17.482 | 17.523 | 12.244 | 10.014 | 7.743 | 11.899 |

| | h A | i A | H o | I o |
|---|---|---|---|---|
| Resistance, | 1 | 1 | 1 | 1 |
| Capacity, | 9.559 | 2.522 | 11.895 | 3.291 |

Now, it appears, by an inspection of these numbers, that the relation which the resistance bears to the capacity (or to the stability, or to the *vis insita* force) is nearly the same in the bodies A o, b A, and c A; that is to say, if their respective resistances be equal to 1, then the capacity or stability, or *vis insita* force; A o, is 17.895 of b A, 17.482; and of c A, 17.523; hence it appears, that the body A o has the greatest advantage, and the body c A the next greatest advantage. But, supposing these bodies to be ships in motion at sea, then it may fairly be inferred, that the body c A would be the worst of the three bodies, because the head-end of c A would not meet with so much lateral resistance to keep the body to windward; and it would meet with more resistance in its *pitching* motion, than either of the bodies A o or B a.

It has been deemed requisite to say thus much respecting the method of comparing the results of the different experiments with the bodies, in order to prevent such as may not have had an opportunity of considering the subject fully, from drawing conclusions, by comparing the resistances only; and,

for this reason, we proceed to make some farther comparisons by way of illustration.

We will therefore compare the resistance of the bodies c A and g A, as found in the Table; whence it appears, that the resistances are nearly the same: but, on considering these bodies as ships at sea, and impelled forwards by the force of the wind on their sails, it will be found, by assuming the resistance of the two bodies respectively, as 1, that the capacity and stability, or comparative power to carry sail, as also the *vis insita* force of the long body c A, would be 17.523, and of the short body g A, 11.899.

It will then be evident, that the long body c A has not only the advantage of being capable of bearing about one-third more sail than the short body g A; but it also has an advantage arising from its great *vis insita* force, or the power of overcoming such resistance as may be occasioned by the undulation of the water (or otherwise) to its direct motion.

It is also to be considered, that the pitching motion is not so quick, nor the areas of vibration, in general, so great, in long ships as in short ships; therefore, the short

ship has not only a disadvantage (as compared with a long ship) arising from the smallness of its *vis insita* force; but also another disadvantage, which is, that its *vis insita* force is destroyed in a much greater degree by a pitching motion, than the *vis insita* force of the longest ship possibly can be by its pitching motion.

Again, it is to be considered, that the power of the wind, by which ships obtain their velocity, is variable in its force and direction, in almost every instant of time. Consequently, the longer ship, which has the greatest *vis insita* force, will have the advantage, as compared with the short ship, of moving with more uniformity in its velocity, and more steadiness in its direct motion; and will, of course, thereby feel the power of the wind upon its sails, in a greater comparative degree than the short ship can upon its sails.

Upon reference to the Figures in the Plate, it will be seen, that the bodies a P A, c P A, k P A, l P A (Fig. 29 to 32) were respectively constructed with differently-formed head ends, but with the same middle part and stern end. Now, for the sake of com-

parison, we shall place the resistance of these bodies, as ships, moving with the velocity of five miles an-hour, as numerators; and the capacities or weights of the bodies under their correspondent resistances as denominators; and as follows:

$$\text{a P A}\left\{\begin{array}{l}\text{Res.}=\dfrac{23.48}{}\\ \text{Cap.}=810.01\end{array}\right.\quad \text{e P A}\left\{\begin{array}{l}\text{Res.}=\dfrac{28.26}{}\\ \text{Cap.}=761.87\end{array}\right.\quad \text{k P A}\left\{\begin{array}{l}\text{Res.}=\dfrac{27.50}{}\\ \text{Cap.}=805.62\end{array}\right.\quad \text{l P A}\left\{\begin{array}{l}\text{Res.}=\dfrac{26.79}{}\\ \text{Cap.}=833.12\end{array}\right.$$

(lb. dec.)

By reducing the above numbers to their lowest terms, the relation which the resistance bears to the capacity, or the capacity to the resistance, will be as follows:

| | a P A | e P A | k P A | l P A |
|---|---|---|---|---|
| Resistance, | 1 | 1 | 1 | 1 |
| Capacity, | 34.498 | 26.959 | 29.295 | 31.098 |

Now, the body a P A, is exactly of the same form and dimensions in its head end, and stern end, and in every respect, except in the length of its middle part, as the body A a. But by comparing the relation which the resistance bears to the capacity, &c. of the body A a, as previously found, with the relation which the resistance bears to the capacity, &c. of the body a P A, as found above, it appears that if the resistance of these bodies A a and a P A, be respectively

equal to one, that then the capacity and comparative stability, and *vis insita* force, of the short body A a, would be 15.175; and of the long body a P A, 34.498. Whence a very considerable advantage appears in favour of the long body, which arises from the difference in the length only.

The Isoceles angular head end e, of the body e P A, and the projecting angular head end k, of the body k P A, were constructed so as to have the same angle of inclination, and the same area of oblique surface in their respective head ends; that is to say, that the hypothenuse or oblique surface of the head end k, is equal to the sum of the two sides, or oblique surface of the head end e.

The oblique surface of the head end k, was made to incline upwards for the purpose of ascertaining the advantage or disadvantage which might arise from its resistance in such position, as compared with the resistance of the head end e, according to its position.

Now, by comparing the relation which the resistance bears to the capacity, &c. of these bodies, as already given, it appears,

that, if the resistance of the bodies e P A and k P A be respectively equal to 1, then the capacity or stability, or *vis insita* force, of e P A, is 26.959, and of k P A, 29.295, which shows an advantage in favour of the body k P A, that is of some moment, and which advantage arises from the form of its head end only. (See the Table.)

The compound projecting angular head l, of the body l P A, (Fig. 32,) was constructed with the same angle of inclination upwards, in the direction of y r, (see the Plate,) as the head end k, of the body k P A, and the horizontal section of its pointed end is an equilateral triangle; this head end was constructed for the purpose of ascertaining the advantage or disadvantage which might arise from such form as compared with the head end k, of the body k P A.

Now, by comparing the relation which the resistance bears to the capacity, &c. of the said bodies, as already given, it appears, that if the resistance of the bodies k P A and l P A be respectively equal to 1, then the capacity or stability, or *vis insita* force, of the body k P A is 29.295; and of the

body 1 P A, 31.098, which gives an advantage in favour of the body 1 P A, arising from the form of its head end only.

*On the Law of the Plus Pressure against Direct and Oblique Surfaces.*

130. If we take the plus pressure of the flat head end I, of the body I o, (Fig. 15,) at the velocity of 8 miles an-hour, which is found equal to 148.25 lb. and reduce it according to the sines of the angles of incidence of the different angular head ends, a d e f, (Fig. 5, 8, 9, 10,); such plus pressures will come out as shown in this Table.

| *Angle of Incidence.* | *Plus Pressure by Experiment.* | *Plus Pressure by Theory, Line of Angle of Incidence to Radius 148.25 lb.* |
|---|---|---|
| ° ' " | *lb.* | *lb.* |
| a= 9.44.10 | =30.67 | . . . . 24.71 |
| d=14.28.40 | . . . 35.34 | . . . . 37.06 |
| e=19.28.15 | . . . 41.71 | . . . . 49.42 |
| f=30. 0. 0 | . . . 51.44 | . . . . 74.13 |

And, by comparing the said plus pressure with the plus pressure as deduced from experiment, and shown here, it must be evident, that the plus pressures, as deduced from experiment, do not follow the law

of the sine of the angle of incidence, nor any regular law that has yet been discovered.

*Experiments on the Resistance of different Bodies, by Charles Gore, Esq. of Weimar, in Saxony.*

131. The following experiments, made at Greenland Dock, by Charles Gore, Esq. of Weimar, in Saxony, may be considered as a valuable supplement to those made by order of the Society for the Improvement of Naval Architecture, to whom an account of the results was represented by the ingenious author.

These experiments were made with great precision, by means of the apparatus belonging to the Society at Greenland Dock.

They tend, like the former, to show, that the first principles of Naval Architecture have been hitherto very imperfectly understood; and certainly lead, as the author has observed, to refute those absurd maxims which have so long governed the constructors of shipping.

The experiments are too clear, too simple, and their application to practice too obvious, to need any farther illustration, than the accompanying figures, and the results which follow:

The bodies, (see the figures comprehended under No. XVII,) were all drawn by one motive weight, *viz.* one pound and a-half, and differed in their velocities as follow:

Figure 1.—Velocity 2.717 feet per second; and weight=25 lbs. 4 oz.

Figure 2.—Velocity 2.664 feet per second; and weight=25 lbs. 4 oz. This being the first body reversed. Therefore 1. exceeded it in velocity by .053.

Figure 3.—Velocity 2.745 feet per second. This body is similar to Figure 1, excepting in the fore part, which is formed with a hollow instead of a round, and which reduces the weight to 23 lbs. 4 oz. being 1 lb. 12 oz. less than Fig. 1, and therefore its velocity exceeds that of Fig. 1 by .028, which is supposed unequal to the defalcation of capacity, and consequent stability. It is also certain, that this form would be more subject to pitching in a sea, by reason of the great inequality of the two ends, whereby the essential counterpoise is destroyed; and, it follows therefore, that the velocity must be diminished, as it cannot be doubted but that the vessel which preserves its equili-

brium in a sea, will pitch less, and must consequently *(cæteris paribus)* be capable of greater general velocity.

Figure 4.—Velocity 2.775 feet per second. Fig. 4 is Fig. 3 reversed, consequently its weight equal; and, though it exceeds the velocity of Fig. 2 by .111, this increase in velocity seems to be produced rather by the decrease of weight, than by the variation of form.

Fig. 4, with its full part forward, as represented, gains upon Fig. 3, .130 in point of velocity.

Figure 5.—Velocity 2.994 feet per second; and, although its weight was 28 lb. 8 oz. it exceeded Fig. 1 by .277.

Figure 6.—Velocity 2.888 feet per second; and its form similar to Fig. 5, with the addition only of a little fulness forward, which increases its weight to 29 lb. 4 oz. It losses in velocity only .106, which is supposed to be counterbalanced by the power of additional sail, which this augmentation would enable the ship to carry.

Figure 7.—Velocity 2.944 feet per second. This is Fig. 6 reversed, by which the velocity increased .056. This body demon-

strates, that fulness abaft, to a degree obvious to a critical eye, on inspection of the Figure, does not impede the motion through the water.

Figure 8.—Velocity 2.837 feet per second. This body has a farther addition or more fulness than Figure 6, whereby its weight is increased to 30 lb. 8 oz. yet loses in velocity only .051 by the last increase, though it still exceeds Fig. 1 and Fig. 2 considerably, notwithstanding 5 lb. 4 oz. increase in the weight.

Figure 9.—Velocity 2.741 feet per second. This is Fig. 8 reversed, by which the velocity is diminished .096. Here the fulness abaft seems to be carried too far.

Figure 10.—Velocity 2.871 feet per second, and similar to Fig. 9, but carried sharper aft, as may be seen in the Figure. The weight 32 lb. 8 oz. Less by .047 in velocity than Fig. 9.

This shows that the after part is here also too round. In this Figure it will be observed, that the extreme breadth is before the centre. This Figure (10) reversed, had a velocity of 2.918, which, though it increased in weight 4 lb, more than Fig.

5, brings the velocity equal to Figure 5, within .076, notwithstanding the considerable increase in capacity, and consequently in stability.

Here it must be observed, that the extreme breadth is abaft the centre as much as Fig. 10 is before it.

Figure 11.—Velocity 2.669 feet per second. This is similar to Fig. 10, but with the same addition forward as abaft, by which it loses in velocity only .202, a loss whose ample compensation will be found in the addition of capacity, and consequent stability to carry sail.

Figure 12.—Velocity 2.997 feet per second, and its weight 38 lb. Similar on the horizontal plane to Fig. 11, but curved on the perpendicular plane on the foremost end, and it exceeded Fig. 11 in velocity .328, which fully compensates the small defalcation of capacity.

Figure 13.—Velocity 2.743 feet per second, and its weight 38 lb. This is Fig. 12 reversed, with the curved end aft. It loses in velocity, compared with Fig. 12, .254. This furnishes an additional argument in favour of placing the sharpness forward.

Figure 14.—Velocity 3.435 feet per second, and its weight 36 lb. It is similar to Fig. 13, but with both ends curved, by which alteration it gains in velocity .692 more than Fig. 13.

Figure 15.—Velocity 1.661 feet per second, and its weight 26 lb. 8 oz.

Figure 16.—Velocity 1.590 feet per second, and its weight 54 lb. This is likewise a parallelopipedon of the same breadth and depth, but twice the length of Fig. 15; notwithstanding which increase in length and weight, the diminution in velocity is only .071. This clearly demonstrates the great advantage derived from length.

Figure 17.—Velocity was 1.806 feet per second, and its weight 50 lb. 12 oz. This is likewise a parallelopipedon.

Figure 18.—Velocity 1.330 feet per second, and its weight 101 lb. 8 oz. This is a parallelopipedon of the same length and breadth, but twice the depth of Fig. 17. It loses, in comparison with Fig. 17, .476 in velocity, which proves that the resistance is increased more by the addition of depth, than by that of length.

We might conclude, from the foregoing experiments, that the best form calculated

for velocity, is a long parallel body terminating at each end in a parabolic cuneas, having the extreme breadth in the centre. Also, that making the cuneas more obtuse than is necessary to break with fairness the curve line into the straight, creates a considerable degree of impediment; and we may be inclined to infer from what has been stated, that the length of ships, which has already been extended with success to four times the breadth, is, with respect to velocity, capable of still farther extension to advantage *.

### *Definitions and Explanatory Remarks on the Motion of Vessels, &c.*

132. The *centre of gravity* of a ship, is that point by which it may be suspended, and the parts remain in perfect equilibrium. It is also the centre of all the forces, or momenta, which press it vertically, or directly downwards, towards the centre of the earth.

The *centre of cavity* or *displacement*, is the centre of gravity of the hollow, or of that part of a ship's body which is immersed in the water; and, also, the centre of all

* See Steel's Naval Architecture.

the vertical force that the water exerts to support the vessel, or to raise it directly upwards. As this centre depends upon the shape of the body immersed, it, of course, varies with every inclination of the ship.

The *meta centre* is that point above which the centre of gravity must by no means be placed; because, if it were, the vessel would overset. This centre, which has likewise been called the *shifting centre*, depends upon the situation of the centre of cavity; for it is that point where a vertical line drawn from the centre of cavity cuts a line passing through the centre of gravity, and being perpendicular to the keel.

The *centre of motion* is that point upon which a vessel oscillates or rolls when put in motion. This centre is always in a line with the water's edge when the centre of gravity is even with, or below, the surface of the water; but, whenever the centre of gravity is above the water's surface, the centre of gravity is then the centre of motion. This must be understood of bodies not perfectly circular; for, if circular and

homogeneous, the centre of motion will be the centre of the circle.

The *line of support* is the vertical or perpendicular line, supposed to pass through the centre of cavity, and intersecting a line drawn perpendicularly to the keel of the vessel, through the point called the *meta centre.*

The *longitudinal axis* of a vessel is an imaginary line which passes horizontally from head to stern through the centre of gravity.

The *vertical axis* is an imaginary perpendicular line, drawn through the centre of gravity, when the vessel is in equilibrio.

The *transverse axis* is an imaginary horizontal line, passing breadthwise from side to side, through the centre of gravity. It is about these axes that every vessel in motion may be supposed to turn. In rolling, she may be supposed to oscillate on the *longitudinal axis;* in pitching, on the *transverse axis;* and in working, &c. to turn on her *vertical axis.*

In illustration of these definitions, let the segment of a circle 1, 2, 3, (Fig. XVIII.) represent the midship section of a vessel's

bottom; WL, the line of floatation; M, the meta centre, as well as the centre of motion, because this is a circle; C, the centre of cavity; G, the centre of gravity; and the line 2, 4, the vertical axis of the vessel, which may be turned round the point M, as on a fulcrum, supported by the centre of cavity. By thus simply considering the vessel as a lever in the direction of her vertical axis, playing round her centre of motion, it is plain, that if the centre of gravity was placed above the point M, being the meta centre too, the vessel would upset; therefore, that the ship may have stability, the centre of gravity must be below this point. And it may be observed, that the further G is removed from the meta centre, the greater must be its force; as the gravity then acts with a greater length of lever, considering the fulcrum of that lever to be at the centre of motion; or, if the weight at G be augmented, it will likewise increase the force; therefore, the force of G may be expressed by multiplying the balance of weight beneath the centre of motion, by the distance of the centre of gravity from the centre of motion.

The centres of cavity and motion (in circular bodies) will ever be in a line perpendicular to the horizon, but the centre of gravity may be either on one side or other of this line. When such a body is at rest, the centre of gravity will be in this line; but, if in motion, it will be diverted from it. Thus, the points M and C will always be perpendicular to WL; but the point G, by the body's rolling, may be on either side; for instance, at g. While G is perpendicularly beneath the centre of motion, its action can only tend to *preserve* this circular body in her erect position; if it be removed to either side, as to g, its action is to *return* it to the erect position; and this action increases as the distance G g, which is the sine of the angle of roll g M G, the distance MG being considered as the radius. Thus, to gain the force of gravity with any roll, as gMG, let the balance of weight beneath the centre of motion be multiplied by the sine of the angle of roll G g.

But the tendency to roll may be also diminished by the shape of the hull. For, let us suppose that the section be allowed more beam, and increased by the dotted

lines. Now, when this vessel is rolled over, it is plain that the cavity will be augmented towards the side L; of course, its centre must remove towards L, say to c; and, if from c be erected a perpendicular to the horizon, it will cut the vertical axis at n, which will, in this case, be the meta centre; above which, if the centre of gravity were placed, the vessel would overset; but, as the centre of gravity is here below it at g, her stability will be increased by the increased distance of G from n, the meta centre; and the vessel will oscillate on the point M, as her centre of motion.

In order to judge of the state of equilibrium in a vessel at rest, let us take into consideration all the forces which act upon it; and, first, the weight by which it is pressed downwards in the direction of the vertical axis. This force, as is evident, must be counterbalanced by all the efforts which the water exerts upon the surface of the immersed part. For, as the vessel occupies a hollow, or cavity, in the water, the quantity of water displaced must be equal in weight to the weight of the body, otherwise they could not be in equilibrio.

This, therefore, is the first great principle upon which is founded the theory of the floating of bodies that swim upon the water; namely, that the immersed part must always be equal in volume to a mass of water of the same weight as that of the vessel. By measuring the volume of its immersed part in the water, we determine the true weight of a vessel.

From what has been said, the whole weight of the ship may be considered as united in its centre of gravity; so that, if it were suspended by a line fastened to this centre, the line would hang in a perpendicular position, in the direction of the centre of gravity to the centre of the earth. A body which floats in a fluid is not, however, supported by its centre of gravity, but by the compression or vertical force of the surrounding water; and the centre of its support is the centre of cavity.

Now, as heavy bodies endeavour, by their gravity, to approach the centre of the earth, in a vertical line passing through their centres; so the pressure of fluids endeavours to carry bodies in a vertical, tending from the centre of the earth towards

their surface. Therefore, in any submerged body at rest, these two opposite forces coincide in the same vertical, acting in a direction quite contrary to each another.

From the principles which have been explained, it follows, that the stability or *trim* of a ship depends, chiefly, upon her construction, supposing the bottom to be homogeneous. This, however, can only happen when her cargo consists of the same materials throughout, as corn, salt, or any goods stowed in bulk; and when her hold is entirely filled. For, if a ship has not sufficient breadth to resist the effort of the wind upon her sails; or, if she is built too high, or too sharp in the floor, her centre of gravity will be too high, and she will be *crank*, or apt to overturn.

## SECTION IV.

### *Of the Forms best adapted for Stability.*

133. It may be observed, that the forms given to the midship-bend of ships are always comprehended between the Figure of a rectangle and that of a triangle; no ship being so full as the rectangle, nor so sharp as the triangle. Experiments, there-

fore, on the stability of these and the included Figures, would produce results by means of which the comparative stability of various forms may be estimated.

With this view, such experiments have been made by Charles Gore, Esq. of Weimar. This gentleman ordered the four bodies to be made, which are represented by Fig. XIX. Nos. 1, 2, 3, 4. Of these bodies, the specific gravity and capacity were precisely equal, although the forms differed extremely. Their materials were in quality the same, and they were balanced in such a manner as to be turned on their respective centres of gravity when afloat, by the application of a small power or weight.

This weight was fastened to a line whose end was made fast to the top of a stick, erected by way of mast in the centre of each body, and passed over a pulley in an opposite stanchion, which worked in a groove to admit of depression so as to be horizontal with the head of the mast when the Figures became heeled or inclined. Thus, the power being always horizontally applied, was similar in effect, to the force of the

wind. To keep the Figures stationary, or to counteract the inclination which the weight, as applied on the opposite side, had to draw the Figures over, two fine lines were fastened to pivots driven into the ends of each Figure at the centre of the line of floatation, and then fastened to hooks projecting from the sides of the cistern.

The results of the experiments, were as exhibited on the engraving. The respective Figures exceeded each other in stability, as they stand numbered on the Plate. But, it is to be observed, that, although No. 1 exceed No. 2 in stability, untill the weights applied amounted to about thirteen pounds and a-half, the excess with more than that weight was with No. 2. That No. 3 was, with every weight, inferior in stability to Nos. 1 and 2; and No. 4 was, with every weight, inferior to all the others. Hence, it appears, that the form of a midship-body, best adapted for stability only, is a rectangular or flat bottom with perpendicular sides; and, the next best adapted is a semi-circle with top sides perpendicular. But, as there exists much difficulty in constructing the rectangle with

sufficient strength, besides its being very ill adapted to heavy seas; as, by the sudden descent in pitching, the bottom will strike the water at right angles nearly, and sustain thereby a violent shock; besides, that it would be leewardly under little sail. The semi-circle, or No. 2, would not only be inclinable to roll much, but would be deficient in capacity for many services. We may, therefore, recommend a midship body constructed in a form between the two, as *most* applicable for ships in general; but, a midship body approaching more towards No. 3 or 4, would have the greatest advantage in point of velocity, and a greater length and breadth at the line of floatation might give even them sufficient stability.

To prove the degree of inclination that the windward side of these Figures had, by suddenly cutting the line that suspended the weight when the Figures were at their utmost inclination, with the top of the side to leeward, as represented, and as even with the surface of the water, it was found that the inclination or roll was nearly in an inverse ratio to the stability, as the windward side of No. 1 heeled 29 degrees;

No. 2, 33 degrees; No. 3, 27 degrees; and No. 4, 23 degrees and a-half.

## SECTION V.

134. Having considered the *resistance* of various forms of vessels in passing through water, and their *stability*, I shall now speak of the forms best adapted to prevent violent and irregular movements, denominated *rolling* and *pitching*, which tend to impede the velocity and to strain the vessel.

135. *Rolling* is that motion by which a ship vibrates from side to side. Rolling is, therefore, a sort of revolution about an imaginary axis, passing through the centre of gravity of the ship; so that the nearer the centre of gravity is to the keel, the more violent will be the roll; because the centre about which the vibrations are made, is placed so low in the bottom, that the resistance made by the keel to the volume of water which it displaces in rolling, bears very little proportion to the force of the vibration above the centre of gravity, the radius of which extends as high as the mast's head. But, if the centre of gravity

is placed higher above the keel, the radius of the vibration will not only be diminished, but such an additional force to oppose the motion of rolling will be communicated to that part of the ship's bottom, as may contribute to diminish this movement considerably.

It may be observed, that, with respect to the formation of a ship's body, that shape which approaches nearest to a circle is the most liable to roll, as it is evident, that if this be agitated in the water, it will have nothing to restrain it; because the rolling or rotation about its centre displaces no more water than when it remains upright; and, hence, it becomes necessary to increase the depth of the keel, the rising of the floors, and the dead wood afore and abaft.

136. The inclination or vibration of the ship lengthwise, about the centre of gravity; or the motion by which she plunges her head and after-part, alternately, into the hollow of the sea, is termed *pitching*. This is a very dangerous motion, and when considerable, not only retards the ship's way,

but endangers the masts, and strains the vessel.

137. That a ship may go smoothly through the water, it will be necessary for her to be so proportioned, as not to be subject to those violent and irregular movements, which tend to impede the velocity, and by too much straining, to destroy the vessel. Great proportional breadth, and sides nearly upright towards the plane of floatation, greatly tend to prevent rolling. To prevent pitching hard, she should have a long keel, a long floor, with little rising afore and abaft. The displacement of the fore body ought to be duly proportioned to that of the after body, and hollow water-lines forward, to be carefully avoided in the construction *.

In this case, proper stowage will be a powerful auxiliary to the accuracy of construction. For, if, to prevent rolling, all the heavier bodies be removed as far as possible from the longitudinal axis; and if, to prevent pitching, all such bodies be stowed as much as possible towards the transverse

* By "hollow water-lines" are meant such water-lines as curve inwards.

axis of the ship; these movements will be found to prevail considerably less than under the circumstances of a different mode of construction or stowage; and the advantages will be great, not merely in obviating the quick oscillatory movements of rolling, but also, the accelerated, or pitching motions fore and aft, so much more to be dreaded, occasioned by hollow seas, hollow water-lines, and great weights at the extremities of the vessel *.

## SECTION VI.

### *Of Steering.*

138. It is evident, that the effect of the rudder must depend much on the cleanness of the vessel's run, so that the water may have an unimpeded passage alongst it. The centre of gravity of the vessel should be as far forward as circumstances will admit; as the power of the rudder is increased in proportion to its distance from the axis of the ship's motion. The stern post should, therefore, be very upright, as is always the case in the French dock-yards. The surface of the rudder should be enlarged, especially

* See Steel's Naval Architecture.

below, as much as can be done consistently with strength, and with the power of the steersman to manage it. When a ship is so loaded, that the keel is not horizontal, but lower abaft, her steering is found to be improved.

## SECTION VII.

### *Improvements in Ship-building.*

139. What I have hitherto said, respects rather the principles than the practice of Naval Architecture: it may be now proper to notice some recent improvements which have been made on the practice of ship-building; I allude to those of Mr. Seppings and Mr. Walters.

### *Mr. Seppings' Improvements in Ship-building.*

140. Although the shape of our ships of war has been gradually improved, little or no advancement had been made within the last century (Art. 101.) in the disposition of the materials which compose the fabric of a ship, untill Mr. Seppings directed his attention to the subject. It is hoped that the following short account of his improvements, will be acceptable to many readers.

The arrangement of the timbers of a ship, when seen on the stocks, bears so obvious a resemblance to the skeleton of a quadruped laid upon its back, that almost all writers on naval architecture have made the comparison. Mr. Seppings, in this respect, follows the example of his predecessors, as being a familiar illustration of the structure of a ship, in order that his readers may more clearly comprehend the advantage gained in strength and stiffness, by the application of his new principle to a frame so constructed.

He tells us, that in a 74-gun ship there rise from the keel, or back bone, and at right angles to it, more than eight hundred different timbers, formed into double ribs, their thickness, on an average, about fourteen inches, and the spaces between them increasing from one to five inches; that this frame is covered externally with planks of different thicknesses, or, to carry on the metaphor, with a skin that is thickest near the keel, and gradually diminishing in substance to the upper ends of the ribs; that the inside of the frame is also lined with planks, over which is another set of short and distant ribs called riders.

To bind the two sides of this skeleton together, there are a multitude of pieces of large timber, seldom of one piece, but mostly of two or three pieces, called beams; serving, at the same time, to support the floors, called decks. These, in a 74-gun ship, are of three tiers. There is also a deck near the bottom, called the *orlop.* These beams are generally fastened to the sides by two angular pieces of timber or iron, called knees; which, being bolted to each beam and to that part of the side of the ship against which the beam abuts, each has thus its separate local and partial fastening.

Between the beams, and at right angles to them, are several short pieces of timber, called *carlings;* and at right angles with these, other pieces called *ledges,* corresponding with the *joists* in the flooring of a house.

The planks or flooring of the deck are laid nearly at right angles with the beams, or parallel with the sides of the ship.

These are the principal materials that compose the body or hull of a ship, and the manner in which they are disposed is, it must be confessed, sufficiently simple. The

ribs form right angles with the keel; the inside and outside planks are at right angles with the ribs; the beams at right angles with these; the carlings the same to the beams; the ledges to the carlings; and the planks of the decks to the ledges, the beams, and the ribs.

This disposition of materials in carpentry, where all the parts are at right angles and parallel to one another, is the very worst that could be assumed for strength or stiffness, and particularly for the latter quality; take a common chair, for instance, with four parallel legs, and four cross bars fixed into them at right angles; it requires no great exertion, however well fastened, to shake it loose, or make it, as it is usually called, *rickety*. An additional bar to each side, or half a dozen bars to each side, placed in the same direction with the first, will add very little to its stiffness.

In the dimensions and disposition of the keel, the ribs, the beams, and the outside planking, Mr. Seppings has introduced no change, but in almost every other respect a new system of arrangement has been adopted. The inside planking, usually

called the ceiling, and the perpendicular short ribs or riders which rested upon it, he has dispensed with altogether. Instead of the first, he fills up all the intermediate spaces between the ribs, with wedges of old ship-timber driven from within and without, which, passing each other, constitute one solid mass, so firmly fixed, as to be in no danger of getting loose; this operation being completed, the ship within exhibits one even surface of solid timber uninterrupted from one extremity to the other; and is so firm and tight, that, without the outside planking or any caulking whatever, the ship would float without danger. These fillings, says Mr. Seppings, occasion no consumption of useful timber, as one-fourth of the produce of slab and other offal now sold as fathom wood, would supply a sufficient quantity for the consumption of the whole navy.

The next operation is, to lay upon this frame, so prepared, from one extremity of the ship to the other, a series of diagonal timbers, whose lower ends abut against the limber strake, and an additional kelson placed on each side, for about 30 feet, in

the middle of the ship, to give support to the main mast. These diagonal timbers are placed in opposite inclinations, from the middle to each end; they are also secured to other pieces running longitudinally, and their upper ends abut against the gun-deck shelf piece, which is a large piece of timber passing round the ship, and binding her together, as it were with a hoop. The diagonal frames are firmly kept in their places by truss-pieces passing between them, and the whole are firmly coaked and bolted to the frame of the ship.

By this operation, the frame work attached to the sides of the hold is divided into rhomboidal compartments, which are again subdivided by the truss-pieces into a series of triangles, giving to the whole fabric the property of an arch, so that no alteration of form can possibly take place in a longitudinal direction, nor can any lateral pressure from without, either from the waves or from grounding, change the form, without forcing the several parts of the frame into a shorter or narrower space.

The same principle of trussing is carried from the gun-deck upwards, from whence,

between every port, is introduced a diagonal brace, in lieu of the short planks commonly used, which had very little, if any, effect in obviating the tendency of ships to stretch or draw asunder their upper works; and, to make the tie complete, and unite the whole fabric into one continued mass, each beam is not only united to the side by a local and partial fastening, but the whole of them are coaked and bolted to the shelf-pieces, by which each beam becomes a component part of the entire fabric; and in order to secure them the better, triangular chocks are placed under all the shelf-pieces in the wake of each, in such a manner as to receive the up and down arm of an iron knee. These chocks being driven tight into their places, act like pillars in supporting the shelf-pieces, the beams, and the deck.

The decks, too, in the new principle, are made subservient towards securing more firmly the beams to the sides of the ship. The planks are laid diagonally in contrary directions, from the midships to the sides, and at an angle of 45° with the beams, and at right angles with the ledges.

The flat of the deck so disposed is connected by coaks to the hooks, beams, and transoms. Along the ends of the deck-planks, next to the sides of the ship, is laid a series of water-ways, bolted through the ship's sides horizontally, and perpendicularly through the deck and shelf-pieces; and thus the whole machine is combined into one uniform mass of timber of equal strength throughout.

We shall next endeavour to form some estimate of the comparative merits of the old and new principles.—And, first, with regard to the filling in.

We have already observed, that, by making the bottom of the ship one compact and water-tight mass of timber, were the outer planking omitted, or any of it knocked off, the ship would not only keep afloat, but be secure from sinking. In the old system, the starting of a single plank would be, as it has often been, fatal.

The ship, by being thus made one solid mass of timber, and less liable to leakage, affords also more facilities of discovering, and infinitely more ease and convenience of stopping, any leak that may occur. In

the old system, very dangerous leaks may happen from various causes, without being perceived, rendering the timber wet, and the pent-up air foul and damp, equally injurious to the strength of the timber, and the health of the ship's company. This cannot be the case in a ship built on the new principle; the leak must be immediately discovered, and may be immediately stopped. The new principle adds to the security of a ship in another way; while the openings are left, the outer plank, of four or four and a-half inches thick, is all that can be said to exist between life and eternity: by filling these openings, there is interposed a thickness of, at least, thirteen inches; which, if not sufficient to stand the striking against a rock, may be considered as a protection against foundering at sea.

If it be true, and we believe it will not be disputed, that timber when freely exposed to, or wholly excluded from, the action of the air, when kept either constantly dry, or constantly wet, will be pretty nearly preserved, an equal length of time, from putrefaction, there can be no doubt, that by exposing freely one surface only to the

air, and excluding air altogether from the rest of the timber, the durability of the ship will be very considerably extended. By dipping the wedges, employed for filling in, in tar, and caulking the seams, all air is completely excluded; whereas, in the old method, a stagnant air was boxed up beneath the ceiling, and between the timbers, the consequence of which was, that all these parts were more or less infected with the dry-rot, and more particularly about the futtock-heads, and the chocks which unite the timbers.

But another very important advantage is obtained by filling in the openings between the timbers. It is well known, that in ships built on the old system, these openings are very soon choked up with an accumulation of filth, which is not only destructive of the timber, but, from the impure air arising from it, prejudicial to the health of the crew. They are the resort of rats, mice, hog-lice, and other vermin, with which a ship is usually infested; and the multitudes of which, in a warm climate, are scarcely to be credited by those who have not had an opportunity of witnessing them.

As capacity is no unimportant object in a man of war, the substitution of the trussed frame for the perpendicular riders laid upon the lining of thick stuff, gains full eight inches more space for stowage; and a tier of iron ballast may be disposed of many inches lower, by which a greater degree of stability will be obtained with less ballast.

Highly as we value the system of filling in the openings between the ribs, and making the whole fabric one solid mass, we think the diagonal trussing of still greater importance, as by it, the constant percussion of the sea is more effectually counteracted, whether it strike the ship a-head, athwart the bow, a-midships, or abaft on the stern; or in other words, the machine opposes more strength to resist the effects of rolling or pitching under every circumstance, than when constructed on the ordinary principles. Nothing can more clearly demonstrate the efficacy of this mode of fastening and tying together the component timbers of a ship, or give a stronger proof of strength and stiffness, than the fact, that ships so constructed, have been found to resist completely the tendency to arch or hogg, from

the moment of their commitment to the element on which they are to move. The reason of this arching is sufficiently obvious; supposing every part of the ship to be equally strong, the central parts, occupying the largest area, sustain the greatest pressure of the water; the two extremities being less supported, and at the same time, having a greater weight of dead wood in them, drop downwards; to prevent their sinking, and the central parts from rising, additional stiffness was required; and this, we conceive, has been very judiciously accomplished by Mr. Seppings, by applying the well known principles of trussing, or a series of triangular braces along the sides of the ship, where the ceiling and perpendicular riders had hitherto been used.

The principle which seems to have governed Mr. Seppings in his new arrangement of the materials, is that of opposing as much as possible to the force acting upon the fabric, the longitudinal direction of the fibres, to give more strength, and to tie together the several parts by a connected series of triangles, to give stiffness.

Dr. Young has published, in the Philosophical Transactions, his remarks upon this

construction. He allows the use of oblique timbers to be good in principle. His arguments sufficiently prove their general utility, in tending to resist a change of figure in the ship; but he seems to doubt of the complete efficacy of the oblique riders and framing in the hold, when employed for the thick stuff of the ceiling. The filling in, however, appears to him wholly unexceptionable, and the braces between the ports to be decidedly more beneficial than the planks for which they are substituted.*

*Mr. Walters' Improvements in Naval Architecture.*

141. Valuable as are the improvements introduced into naval architecture by Mr. Seppings, Mr. Walters conceived that there was room left for farther improvement, and that a complete remedy for hogging still remained a desideratum. Having, as he conceived, contrived means for effectually obviating this defect in all ships. He obtained a patent for his invention, of which the following is an explanation.

* See Philosophical Transactions for 1814, also the Quarterly Review, No. XXIV, in which Review may be found testimonies of the practical results of Mr. Seppings' plan.

The mechanical principle upon which this improvement is founded, is that of forming a complete and integral truss or support from the centre of gravity (whence the strength of the whole structure should as much as possible be derived), and so connecting the parts together, by embracing the entire fabric, that any tendency to a change of figure may be powerfully counteracted, and as much strength be given as the nature of materials will permit.

The frame or skeleton of a ship being constructed in the common way, a principal frame A, (Fig. XX. No. 1 and 2,) constructed of metal, or of wood and metal, is introduced in the space between the ribs, intersecting the vessel athwart the centre of gravity, connected across the ship by a tie-bar or beam B, (No. 2,) and having the internal diagonal braces C, C. Also from the upper part of the said principal frame, the braces D D, (No. 1,) constructed of metal, are let in flush upon the outside and bolted to the frame timbers, and carried down in an inclined direction (being that of the shortest

distance over the curved surface *) to the lower part of each extremity of the vessel, and connected each with its opposite one, in the concave parts of the bottom, by bolting through from one to the other, or by any other convenient method. Thus, the whole frame of the ship is firmly connected together, and the weight of either end (supposing the ship supported under the centre of gravity) is counterbalanced by the other end, while the vertical strain, proceeding from the weight of the whole fabric, is transferred by the tension upon the braces C, C, to the principal frame A. And also for the more perfect stiffening of the hull, (when the spaces between the timbers are not filled in solid,) and thereby obtaining a counter-resistance to the weight of the middle, (supposing the vessel supported at the ends,) chocks or strutting pieces of timber scantling are tailed in between frame and frame behind or within the braces, which acting as arches, when confined by the braces, discharge the weight of the vessel

* The utility of keeping the braces in the direction of the line of *shortest distance* is, that it presents the direct tension of the braces to every endeavour of the ship to change her figure, and prevents the possibility of the braces being moved by any force into a new position.

upon the butments at each extremity, which completes the truss. And it will appear evident, that so long as the truss remains perfect, not any weight or pressure can alter the relative position of any of the parts, whether the vessel is horizontal or inclined, unless caused by some shock that would go near to effect the total destruction of the whole fabric.

The foregoing description being confined to the method of trussing smaller ships or vessels, the manner of extending this system (which, with a little modification, is applicable to ships of the greatest magnitude) is shown by No. 3, in which A is the principal frame; and B B the braces, as already described; C C are auxiliary braces; D D minor principal frames, one in the fore and the other in the after part of the body; E E are minor braces; and F is an horizontal brace, connecting the heads of the minor braces, and forming a kind of longitudinal hoop to the upper part of the structure *. Chocks or strutting pieces are also tailed in at the back of these braces,

* As the tension upon the horizontal brace F is in the direction of the planking, this brace is not necessary to be used except in cases where great additional strength is required.

similar to those before described, when the spaces are not filled in solid.

In ships of war, the disposition of the principal braces ought to be so regulated as to be but little exposed to be shot away, and auxiliaries should be employed below low-water line, for additional security.

The braces before described, are made of flat bars of metal in pieces of convenient length, so adjusted that the parts at which they are joined together, fall in the spaces between the ribs of the vessel, being connected by scarf joints wedged up for the purpose of equalising the tension. The outer surface of the braces is kept flush with the frame timbers, and the bolt-holes in all of them are countersunk to receive the heads of the bolts, so that no part may present any obstruction to the planking.

In addition to the security afforded by this principle of trussing, in constructing the ribs, Mr. Walters affixes upon the sides over each butting joint of the timbers of which the rib is composed, a plate of iron or other metal extending above and below it, and bolted through the rib, by which means the ribs acquire great additional strength;

an object of the first importance, even if only partially employed in assisting the weaker parts, and protecting those most exposed to injury; as in cases of a ship's grounding, it commonly happens that the floor timbers are forced in at one end, and the first futtocks broke off, while, by the tendency of the sides to sink, a transverse curvature is occasioned by a failure of the parts situated near the head of the floor timbers. In many other respects, the employment of these iron clamps will be found of the most essential service.

Such is the general arrangement and application of this invention to practice. It is a system of framing, which resembles, in some of its qualities, and in its effects and operations, the trussing employed in the construction of roofs, bridges, and other framed carpentry of great span, so that a vessel to which it is applied, may not improperly be called a trussed ship or vessel; and this powerful support, superadded to the usual fastenings, must, it is presumed, infallibly produce the great objects proposed, of preventing the depression of the two ends, and the butt ends and seams of the

plank from opening, and also give general strength and security to the vessel.

Mr. Walters states, that the advantages resulting from this improvement are,

1st, That the durability of vessels will be increased, thus precluding the early and frequent repairs rendered necessary by the radical weakness of the present mode of construction.

2dly, That by means of the powerful support effected by the truss, the filling timbers between each rib may be omitted, thereby making a very considerable saving in the first cost, after allowing for the expense of the truss.

3dly, The great benefits eventually to accrue to the mercantile world are, first, a reduction in the charges of freight, proportioned to the diminution of the expense of building, the less frequency of repairs, and the comparative greater durability of the vessel; secondly, a more perfect security of the cargo from damage; and thirdly, a lower rate of insurance.

4thly, The saving annually to their relatives, and to the community, a great number of valuable lives *.

* See Philosophical Magazine, April 1815.

## SECTION VIII.

142. It requires no arguments to prove the utility of using well seasoned timber in ship-building, and there can be no question that winter-felled timber is far superior to that cut down in the spring. There would also be great propriety in building ships under cover. This practice has, of late, been introduced in some of our royal dock-yards. The Swedes build all their ships of war at Carlscrona, in covered docks. The slips in the naval arsenal at Venice, are roofed, and the French have a covered dock at Brest.

Mr. Pering * is of opinion, that tree nails are very imperfect instruments for confining the planks of a ship to her sides, and proposes substituting copper bolts. Their advantage consists, in the first place, in giving a less wound to the plank and timbers, and thereby allowing a reduction of the scantling, or size of the timbers; and, in the second, in giving more security, firmness, strength, and, consequently, dura-

* See "A brief Inquiry into the Causes of Premature Decay in Ships, &c." by Richard Pering, Esq.

bility to the machine. Many parts of ships are now copper-fastened, but Mr. Pering disapproves much of the common practice of clenching them, by battering the ends of the bolts over a metal ring, and illustrates its defects, by supposing the case of a coach fastened together in the same way as the ship-wright fastens a ship, and asks, how long will that coach run over the stones? and demonstrates the superiority of the mode really employed by coach-makers, that of compressing wood into wood, by means of a *screw* instead of a clench.

## SECTION IX.

143. Ships on the common construction, are found in many particulars very defective; various methods have, therefore, from time to time been proposed to remove some of their imperfections, and it would be an endless task to enumerate all the different inventions for this purpose.

In 1663, Sir William Petty constructed a double ship, or rather a single ship with a double bottom, which was found to sail considerably faster than any of the ships with which it had an opportunity of being

tried. Her first voyage was from Dublin to Holyhead, and in her return, she turned into that narrow harbour, against wind and tide, among rocks and ships, with such dexterity as many ancient seamen confessed they had never seen the like. This vessel and seventy more, were lost in a dreadful tempest *.

This subject was again renewed by Mr. Gordon, in his "Principles of Naval Architecture," printed in 1784; and soon after, double ships were actually built by Mr. Miller of Dalswinton. It has already been mentioned (Art. 94.) that double vessels had been adopted in some cases in America, for steam boats.

Of all the vessels in the world calculated for fast sailing, the flying proa of the Ladrone Islands, is perhaps the most striking example. These islands lye all nearly under the same meridian; a meridian under which the trade winds almost constantly prevail. This circumstance would render any voyage extremely tedious, if attempted by a vessel of the common European form, from the

* See Birches' History of the Royal Society, vol. I. p. 183, and Encyclopædia Britannica, Art. Ship-building.

wind, during the whole voyage, being constantly on the beam. According to the Author of Commodore Anson's Voyage, "with a brisk wind, these proas will run nearly twenty miles in the hour." The head and stern are of the same form, because the proa never puts about, but, at pleasure, sails with either end foremost, the same side being constantly exposed to the wind; which side is built rounding, not materially varying from the common European form. The lee side, however, is totally flat; and, owing to the extreme length of the vessel, with its want of breadth, would immediately overset, but for the following curious contrivance. An out-rigger is fixed on the weather side, extending some distance over the water, and, at its extremity is fastened a log of wood, made in some degree in the form of a boat, which prevents the proa from falling over to leeward, under a pressure of sail; and preserves it from all risk of oversetting. For a more particular description of this singular piece of nautical mechanism, the reader is referred to "Anson's Voyage," "Charnock's History of Marine Architecture," and "Steel's Elements of Naval Architecture."

The vessels of the Dutch, and several other northern nations, are so constructed as to draw very little water, and, consequently, are apt to fall to leeward, when the wind is not considerably abaft the beam. To remedy this inconvenience, the mariners of those nations adopted the invention of the lee-board, which being drawn up, or let down into the water at pleasure, according to the tack on which the vessel may happen to be (one being fitted on each side) from its hold on the water, occasions that resistance to the impulse of the side-wind, which enables the vessel to make head-way with much less deflection from its course, than would take place were such addition wanting. The invention of sliding keels for the same purpose, seems to have arisen from that of lee-boards. See Steel's Naval Architecture.

## PART VII.

*Miscellaneous Observations.*

144. The steam boat D (Art. 15.) has her paddle-wheels placed much nearer the bow, in other words, much farther forward, than in any of the other vessels on the Clyde. It might be worthy of investigation how far this circumstance operates in producing greater velocity. The fact is, that she goes with greater speed than the other steam boats, whether in smooth or in rough water. The hull is much better adapted than the others for a heavy sea, her bottom being formed somewhat like a good-going sloop or cutter. She draws about four feet water.

It appears to me, that placing the paddle-wheels forward, may possibly operate in favour of the vessel's speed in two ways: 1st, when one vessel tows another, the towing rope is generally fastened to the bow of the aftermost vessel. Were it fastened near the middle of that vessel, or still farther

aft, it is obvious, that without a very powerful helm, she could not be kept steadily in the course of the towing vessel. Now, there is a great analogy between this case and that of a steam boat, the situation of the centre effort of the paddle-wheels, acting on the helm in the same manner as the point of fixture of the towing rope. 2d, It has already been observed, (Art. 112.) that when a vessel is in motion, the water heaps up on her bows, and occasions a considerable hinderance. Now, I think, it is not unreasonable to suppose, that when the paddle-wheels are working near the bow, their rapid action serves to lower the surface of this anterior wave, and thereby lessens the resistance to the vessel's motion.

145. In Fig. XXI. (No. 1, 2, 3, 4,) is represented the machinery as constructed in the steam boats E and D.

The boiler is placed on one side, and the steam engine on the other. The steam engine communicates motion by a crank to the fly-wheel shaft, on each end of which there are spur-wheels. On the inner end of the axle of each of the paddle-wheels,

there is a spur-wheel, which receives its motion from the spur-wheel on the fly-wheel shaft.

Fig. XXI. No. 1, Profile of the steam engine and boiler.

Fig. XXI. No. 2, Plan of the boiler, steam engine, and paddle-wheels.

Fig. XXI. No. 3, Elevation of the nossels.

Fig. XXI. No. 4, Vertical section of the air-pump and condenser.

AA, The boiler.

B, The steam-pipe.

CC, The nossels.

D, The cylinder.

E, The air-pump.

FFFF, The beam.

GG, The connection-rod.

HH, The cranks.

II, The fly-wheel.

KKKK, The spur-wheels.

LLLL, The paddle-wheels, in which the paddles are placed obliquely.

*a*, Small forcing pump for feeding the boiler. The quantity of water forced into the boiler is regulated by a cock; what is superfluous goes off by a waste-pipe, which has also a cock.

The cylinder is 22 inches diameter, and the stroke of the piston two feet, making 45 strokes per minute.

The paddle-wheels are each 8 feet 9 inches in diameter, having paddles 3 feet 10 inches in width, and 1 foot 8 inches in depth.

Their velocity, at the circumference, is 880 feet per minute, equal to 10 miles an-hour. The velocity at the mean depth of the paddle in the water is 712 feet per minute, equal to 8 miles 100 yards an-hour.

146. The engines used in the steam boats on the river Clyde, although of various constructions, are all on one principle, namely, that of Mr. Watt. The same, I believe, is the case with those in America. In one situation in England (see Art. 89.) high pressure engines are used in steam boats, on Mr. Trevethick's plan.

High pressure engines are objected to, from the supposed danger of explosion of the boilers, but they have of late been much improved at the mines in Cornwall, and also in other places, from the necessity there is for using them on account of their

lightness for steam carriages, which has much lessened the risk of explosion. But, in other respects, high pressure engines, possess these decided advantages over condensing engines; *viz.* 1st, Simplicity of construction; 2d, Occupying little space; and 3d, In their being much lighter.

147. It is probable, that another source of employment will arise to steam boats; that of towing ships, whether outward or homeward bound. In certain states of the markets, the saving of a tide might make a most material alteration on the value of a cargo. Towing of ships has already been tried with good effect.

148. There are two of the steam boats at present on the Clyde, constantly employed in carrying goods. It is the opinion of many, that the most advantageous method of carrying goods, would be to have a separate boat for the engine, and to tow lighters.

This plan would be attended with these advantages; *viz.* no time would be lost in loading and delivering the cargo, and the

machinery would always work at the same depth in the water. At present, without a power of altering the depth of the paddles, or of the wheels themselves, they must often be at an improper depth in the water; and in order to obtain this power, the apparatus must be made more complex.

149. Some are also of opinion, that the best way for carrying passengers, would be to have the passage boat towed by a boat carrying the steam engine; and that the small loss of power which the use of two vessels would, in some cases, occasion, would be more than compensated by the towing boat working always at the same depth in the water, and by the greater cleanliness and quietness of the separate vessel for the passengers.

An ingenious mechanic suggests, that four wheels would work with more advantage than two, provided the foremost pair were made to act so as to impel the water a little outwards, instead of parallel to the sides of the vessel, as at present. Some of the American steam boats have four paddle-wheels.

150. To illustrate the effect which drawing in the water may have, in Mr. Linaker's plan, I may mention the following curious fact; that if a hole be made under the water-line in the bow of a boat, and the water be allowed to enter freely, the boat (in stagnant water) will move forward until it rise to the same level with the surface of the water without.

The greatest difficulty in Mr. Linaker's plan, is to get sufficient velocity in the water, at the ingress and egress of the trunks, without losing much power. The piston of a steam engine moves only at the rate of 200 feet per minute, equal to 2 miles 480 yards an-hour; a velocity evidently far too slow for the water in the trunks; and if velocity were obtained by making their area much smaller than the working barrel, the resistance increasing in a high ratio with the velocity, there would be a very great loss of power.

151. Since Article 17 was written, the steam boats plying on the Clyde have increased to eleven, and several more are in progress. It is supposed, that one day this season, 1815, that from 1000 to 1200 persons left Glasgow, on board the different steam boats.

## *PART VIII.*

Since Part III. was printed off, I have obtained the following additional information respecting Steam Navigation in England.

*The Thames.*

152. The steam boat mentioned as fitting up in the Surry canal dock, (Art. 88.) was tried with a wheel 8 feet wide, placed in a space near the centre of the vessel, open at bottom. There were channels to convey the water from the bow to this well; but the well terminated square behind the wheel. Upon trial, this plan was not found to answer; afterwards, a pipe was introduced about 1 foot diameter from the square well, but this experiment having been also unsuccessful, the wheel was removed, the well closed, and external paddle-wheels adopted. This vessel now plies between London and Margate.

*The Yare.*

153. The steam boats at Yarmouth have high pressure steam engines fixed in the midships. The steam from the engine is conveyed into the river, by a pipe having valves. The paddle-wheels, like those on the Clyde, are on each side of the vessel.

The first steam boat on this river, was introduced by Mr. Wright in 1813. The vessel he used had been a French row-boat privateer. In still water, her speed is about 6 knots an hour.

The Defiance plies between Yarmouth and Norwich; has two boilers, and a horizontal cylinder in each; the paddle-wheels external. Speed, in still water, is about 5½ knots an hour.

*Ouse and Humber.*

154. There is a steam boat plying between Hull and Selby, a distance of about 60 miles.

*The Orwell.*

155. About the month of August, this year, (1815,) a steam boat began to ply on the Orwell, between Ipswich and Harwich. The vessel is flat bottomed. The engine, 10 horse' power; paddle-wheels, external.

156. Since this sheet went to press, I have been favoured with the following information.

"At present, there are five steam-boats on the Thames.

"1. *The Thames* (originally the Argyle, see Art. 19.) 14 horse' power, plying between London and Margate; reckoned the best boat. The paddles alternate with each other, and are set at an angle of 45°.

"2. *The Regent*, 16 horse' power, paddles sit square, with rims like an overshot wheel; is expected to ply between Chatham and Sheerness. She was first built for the wheel to work in the middle; but this not having been found to answer, has been altered.

"3. *The Defiance*, 12 horse' power, to Margate, with double horizontal cylinder engine.

"4. A boat which plied between London and Gravesend was laid aside, on account of a law-suit, as she was not worked by a privileged person. Such a person has now taken her, and she will soon start again, with a new 12 or 14 horse' power Scotch engine; being originally fitted with a high-

pressure engine. The wheels of this have rims, and the paddles swing like stop butt hinges.

"5. A boat with double keel, 6 horses' power, is now building above Westminster Bridge; paddles upright; said to be for London and Richmond.

"6. Mr. Maudslay built a small boat last year for Ipswich and Harwich, 16 miles, done in 2¼ hours, but against a strong wind in 3 hours. This has six frying-pan paddles set square, without rims.

"I have been informed, by letter of August last, from Gainsbro', of a steam boat from thence to Hull, which performs the voyage, 50 miles, in 8 hours. And this week, from Canada, that, at present, there are two steam vessels on the river St. Lawrence; one, 48, the other, 36 horse' power; which go at seven miles an-hour; measure about 170 feet long, and 30 feet wide! That another 48 horse' power vessel will be launched next year on that river. So that one may go by steam from Quebec to New York, in 8 days, with a short land carriage."

157. A steam boat was lately built at Petersburgh, in Russia, which has been honoured by the presence on board of the Empress Dowager.

158. A steam boat is preparing to attend the expedition, under the command of Captain Tuckey, of the royal navy, going to Africa, with a view to trace the course of the rivers Congo and Niger.

# APPENDIX.

## No. 1.

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*Account of a Steam Boat invented in* 1737.

159. Among the various important mechanical uses of steam, none promises to be more useful to mankind, than its application to the conveyance of vessels. This it is now made to accomplish without the aid of wind or tide, not only in rivers and narrow channels, but also in broad friths, and almost in the ocean. The application of steam to mechanical purposes has now been known for upwards of a century. It was in 1705 that Newcomen took out his patent for the steam engine. In 1712, it was first used in the collieries: and, in 1720, it had come into general use. In 1725, Mr. Wauchope of Edmonstone contracted for one with John Potter, Engineer. But the following fact, for which we are indebted to an intelligent correspondent, is not generally

known. So far back as 1737, there was published the description of a *steam boat.* The plan of it is contained in a small pamphlet, under the following title: "A Description and Draught of a new-invented Machine for carrying vessels or ships out of, or into any harbour, port, or river, against wind or tide, or in a calm. By Jonathan Hulls. London: Printed for the Author, 1737. Price 6*d.*"

The title of this pamphlet will exhibit the limited view in which the author regarded his plan, being rather for overcoming local difficulties, than for being the continued instrument of the vessel's motion. He discusses the question, Whether the machine should be placed within the vessel to be thus towed; or Whether it should be fitted into a boat, which, being attached to the vessel, might draw it along. For several very good reasons, he prefers the latter; so that his plan is exactly that of a *steam boat.*

In explaining the process followed, the author begins by demonstrating a number of problems in mechanics and pneumatics, upon which his machine is founded. He then proceeds, in the following terms, to describe the mechanism employed:

"In some convenient part of the tow-boat, there is placed a vessel about two-thirds full of water, with the top close shut; this vessel being kept boiling, rarefies the water into steam; this steam being conveyed through a large pipe into a cylindrical vessel, and there condensed, makes a vacuum, which causes the weight of the atmosphere to press on the vessel, and so presses down a piston that is fitted into this cylindrical vessel, in the same manner as in Mr. Newcomen's engine.

"It has been already demonstrated, that when the air is driven out of a vessel of 30 inches diameter, (which is but two feet and a-half,) the atmosphere will press on it to the weight of 4 ton 16 cwt. and upwards; when proper instruments for this work are applied to it, it must drive a vessel with great force*."

---

## No. 2.

*Extract from the Marquis of Worcester's Century of Inventions.*

160. "An admirable and most forcible way to drive up water by fire, not by draw-

* See Scots Magazine, &c. for March, 1815, p. 164, 165.

ing or sucking it up upwards, for that must be, as the philosopher calleth it, *intra sphæram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessels be strong enough; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the broken end, as also the touch-hole; and making a constant fire under it, within 24 hours it burst and made a great crack: so that having a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other. I have seen the water run like a constant fountain-stream forty feet high, one vessel of water rarefied by fire driveth up forty of cold water. And a man that attends the work has but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively, the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

## No. 3.

161. I am indebted to Mr. Matthew Murray of Leeds, for the following rule which Messrs. Fenton, Murray, & Wood adopt for calculating the weight of the fly-wheels of their steam engines.

### RULE.

Multiply the number of horse' power by 2000 *, and divide it by the square of the velocity of the circumference per second, the quotient will be the weight of the fly-wheel in cwts.

#### EXAMPLE.

*To find the weight of a fly-wheel for a 20 horse' power engine; wheel,* 18 *feet diameter; and* 22 *revolutions per second;* †

*Diam. Circum. Revol.*
$18 = 56 \times 22 = 1232 \div 60 = 20\frac{1}{2}$ feet per second.

*Momentum for a* 20 *H. P. engine.*
Then $20\frac{1}{2}^2 = 420\frac{1}{4}$ and $40,000 \div 420\frac{1}{4} = 90\frac{4}{10}$ cwt. weight of the wheel required.

* This number is the result of Mr. Murray's experience.

## No. 4.

162. Mr. W. Dryden (of whom Dr. Olinthus Gregory, in his "Mechanics," makes respectable mention) favoured me with drawings and a description of the steam engines manufactured by Messrs. Lloyd and Ostell, Gravel Lane, Blackfriars Road, London; but I regret that, without increasing the expense of this Treatise considerably, by additional plates, I can only give the following extracts from his description.

"The boiler is of cast-iron, and has the fireplace within side of it, contained in a wrought-iron flue. There is a hole in one end of the bottom and end of the cast-iron boiler, where the wrought-iron flue is joined that contains the fireplace. A plate which contains the fire door, is screwed on front. The bolts go through the plate, and wrought-iron flanches of the flue, and the end of the cast-iron boiler. The joint is made with iron cement. When the flue

wants repairing, it can be easily taken out of the boiler, which makes it more convenient to replace any decayed part in the flue. As for the cast-iron boiler, it will last a great number of years. It may stand on pieces of timber, or on a bed of brick work, a little higher than the floor, if it can be conveniently got. The ash pit is built round with brick. The inner end of the flue has a branch which joins to the side of the boiler. The heat is conveyed round the boiler, by a brick wall, on one side, the boiler itself forms the top of the flue. A plate is bolted on the front, to carry the flue across, above the fire door. There is about 18 inches depth of water under the flue, except at the fireplace. The bottom of the flue round the boiler, is filled up, part of the height, with sand or rubbish. This sort of boiler answers extremely well, is durable, and saves fuel. The fireplace is nearer one side than the other, in order to give room for a man to clean it out, and also to give some length to the branch that joins the boiler, for the sake of unequal contraction and expansion of the different metals by the heat.

The piston is not packed with hemp or cotton in the common way, but has rings of brass or gun metal formed in pieces, nicely fitted to the cylinder at the extremity, and well jointed to each other, and to the bottom and cover of the piston. The bolts that screw on the piston-cover should be the same sort of metal as the rings, so that they may expand equally with the heat. Between the inside of the brass rings and the body of the piston is placed a quantity of slight spiral or bent springs. These springs keep the brass rings always steam-tight to the cylinder, even although the cylinder may not be truly bored. This sort of piston is strongly to be recommended, for it answers extremely well, works with considerably less friction, and never wants any repair. No time is lost with packing; and, beside the saving of hemp and tallow, no space need be left in the length of the cylinder for the tightening or screwing down the piston cover, which also saves steam.

The steam valves differ also from those commonly in use, that is, in place of their being placed perpendicularly over each other,

they are placed at the side of each other, one above the steam way, and one below. The four valves and seats are exactly alike. Each has a rod attached to it by a common joint on the upper side; which joint admits the valves to shut close, although the stuffing boxes may not be packed equally on all sides; which is very often a defect of the valves made in the common way. On the top of each of the rods, above the stuffing boxes, are double collared brasses, which receive the lifting fingers, which are made fast on the rods. Those rods are lifted by the eccentric motion from the crank shaft. When the one rod is lifted, the feeding valve and the exhausting valve will also be lifted; and when the other rod is lifted, it will lift the other feeding valve and exhausting valve. The weight of the rods and valves is quite sufficient to shut them; as the eccentric motion will let them down as gently as it raises them. The seats of the valves are made fast in their places with iron cement, which answers the purpose very well. I have made a great many engines with valves in this way, and never have known an instance of any of them giving way,

although some of them have been wrought for upwards of five years; but, even when they need repair, it is more easily done than in the valves made in the common way. The slides, which are much used in place of valves at present, are not to be recommended, not even where there is good soft water, although with that they will answer better than with hard or mineral water. Experience has taught me, that they will not keep in good order long. Indeed, it is reasonable to suppose, that such surfaces as these, where there is such a pressure and impossibility of keeping oil or grease to their rubbing surfaces, must wear a great deal more than a valve that is lifted up and let down again without rubbing. And when the slides get out of order, it is very difficult to put them right again, which is not the case with the valves above described; and, I believe, that the valves, as above, can be made at less expense at the first erection than the slides can. All the other parts of this engine are made nearly in the common way."

## No. 5.

163. With a view to correct a notion which very generally prevails with regard to the towing of timber, I have made the following extract from a paper written by Charles Gore, Esq.

"In regard to the experiment I have made upon the spar of timber, I found, upon repeated trials (performed in the presence of an eminent ship-builder, who considered the experiment as fairly tried), that the small end always met with a great deal less resistance, being prevented from shearing, though otherwise floating at liberty; which has induced me to believe that the idea, generally received as a maxim, and, I believe, constantly practised, has been occasioned by the manner in which it is done, with a certain length of rope to the stern of a boat, which permits the spar to sheer, which it is more subject to do with the small than with the large end foremost *."

* See Proceedings, &c. of the Society for the Improvement of Naval Architecture, to September, 1792, p. 8.

*ERRATA.*

Page 26, line 2, *for* cylinder, *read* cylinders.

28, — 10, *for* and Fig. I. No. 5, *read* and Fig. II. No. 5.

26, — 8, *for* cabin, *read* cabins.

31, — 5, *for* bateaus, *read* bateaux.

75, — Foot note—*for* with which I have here made free, *read* of which I have here made free use.

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JAMES HEDDERWICK, PRINTER, GLASGOW.

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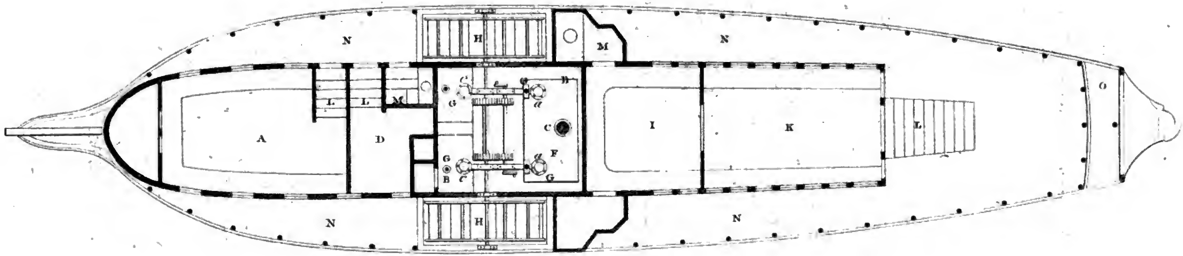


Drawn by R. Stuart Meikleham & Engraved by ...

PLATE III.

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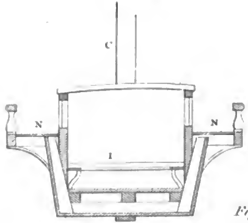


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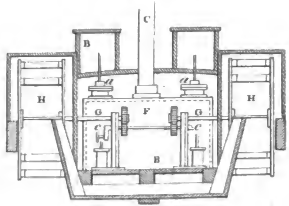


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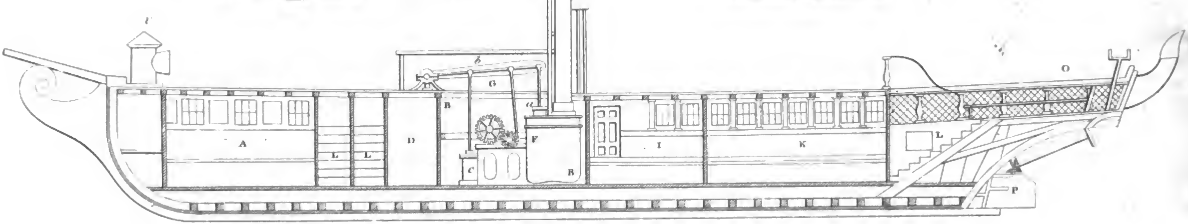


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PLATE IV.

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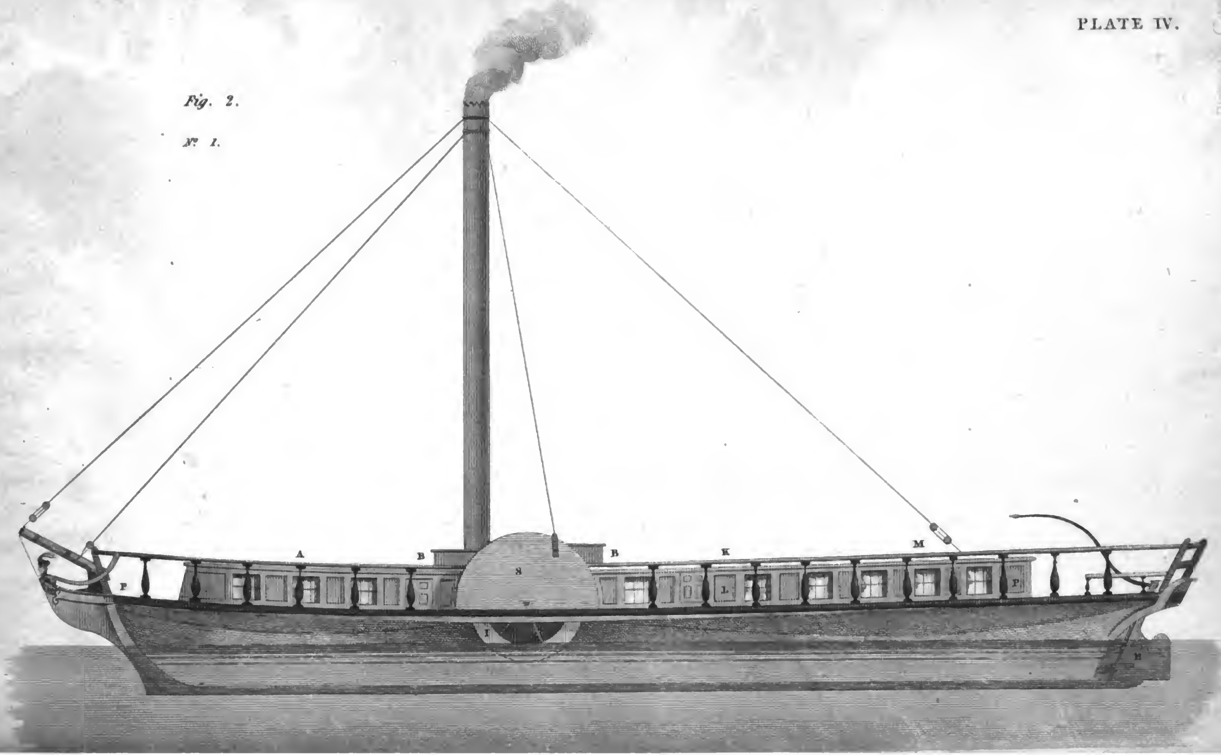

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Fig. 2.

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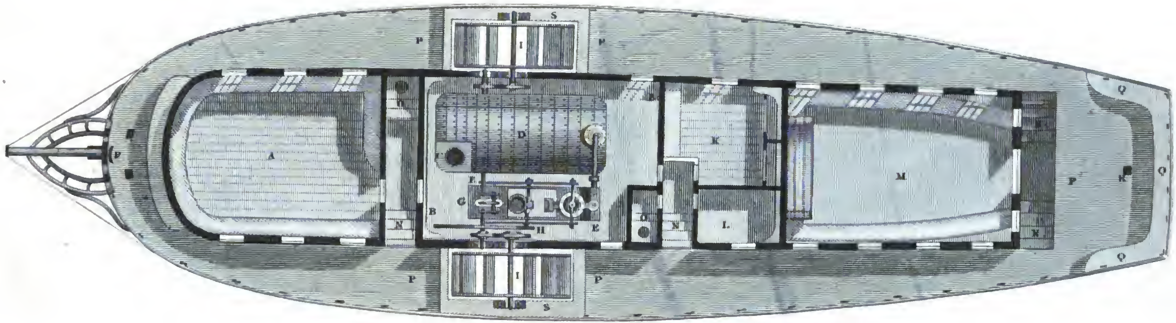


Drawn by R. Buchanan

Eng^d. by R. Kirkwood

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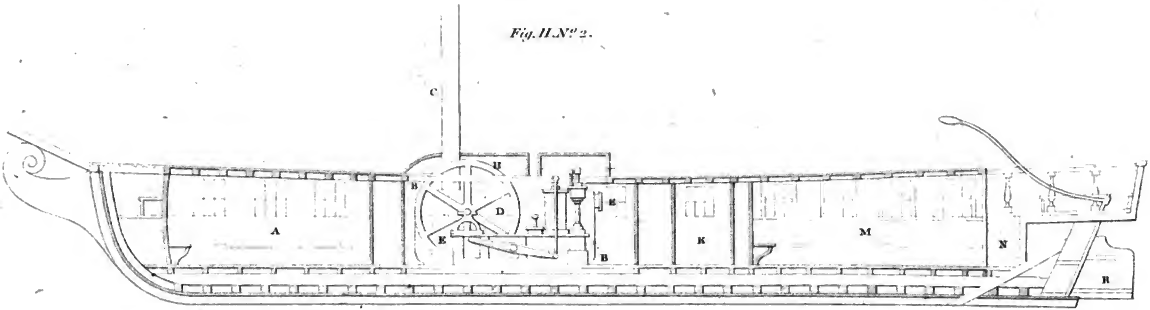


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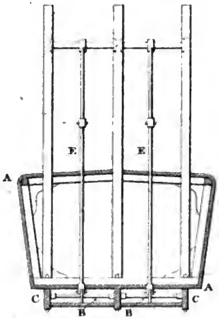


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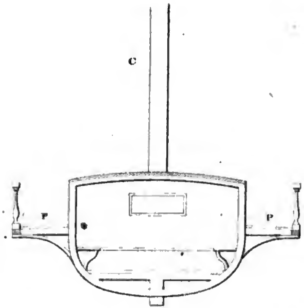


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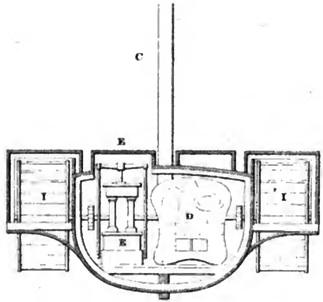


*Drawn by R. Stuart Meikleham, & Engraved by J. B. Taylor.*

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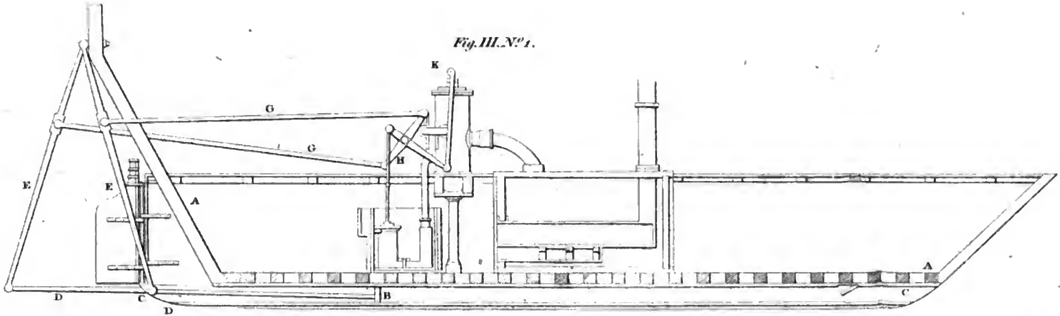


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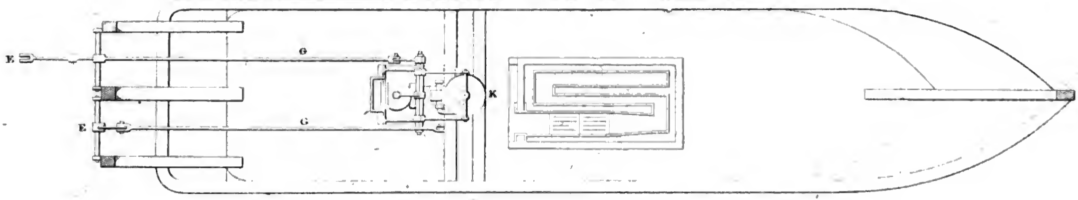


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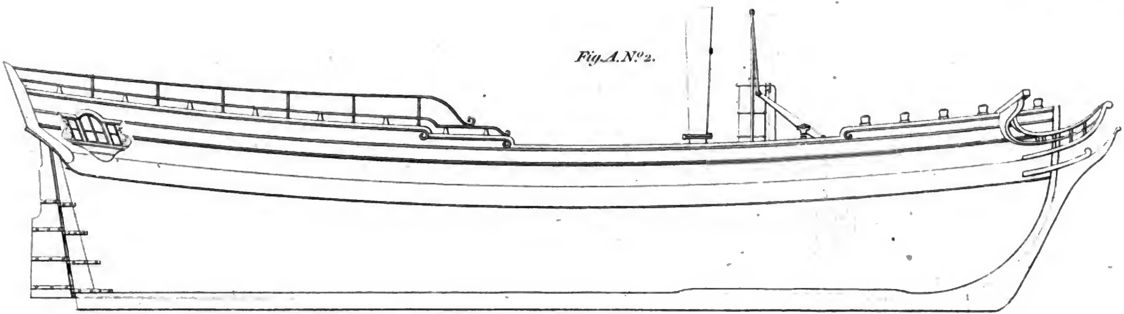

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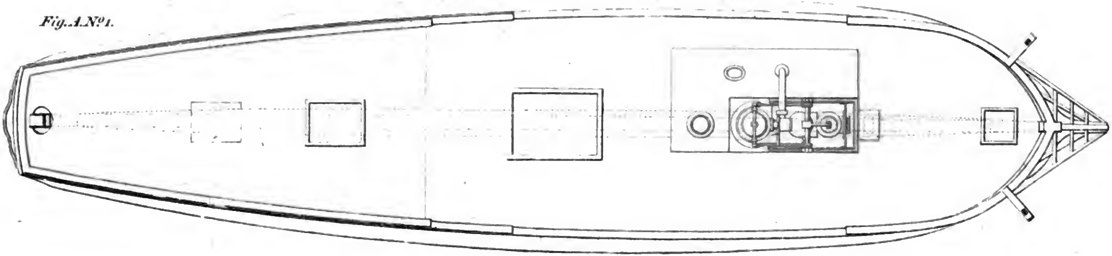

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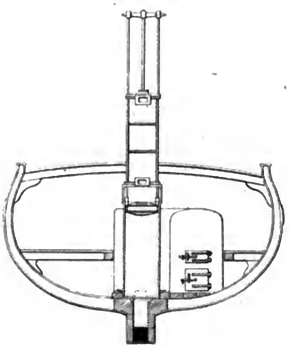

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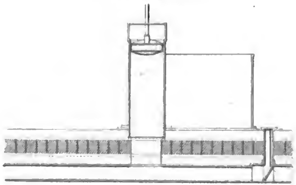

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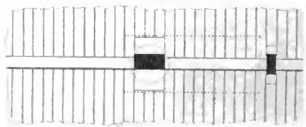

Fig. A. No. 7.

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Edge View of Paddle Wheel

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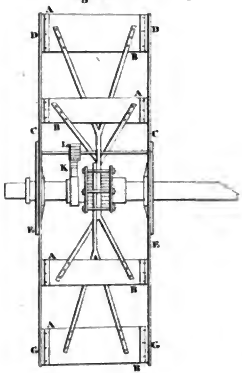


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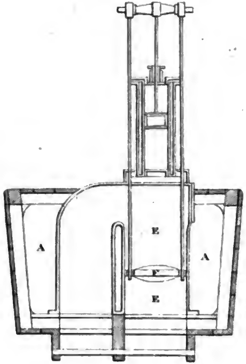


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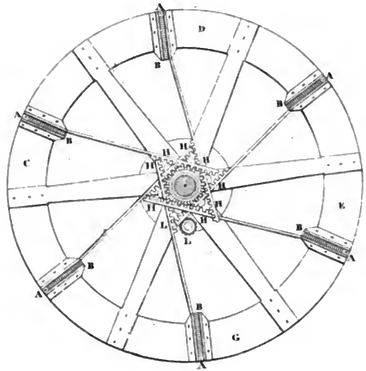


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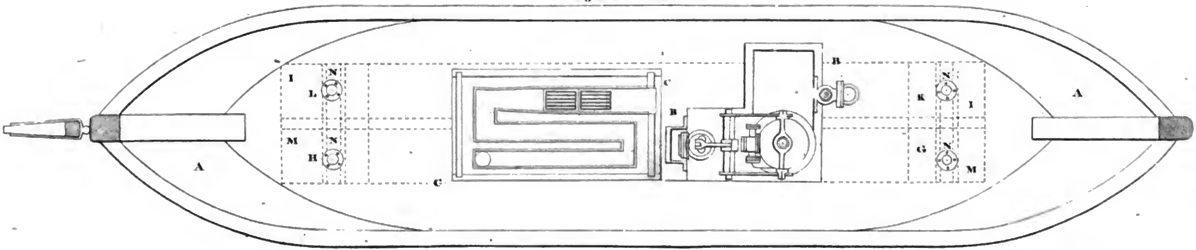


J. Moffat Sculpt

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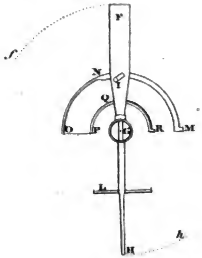

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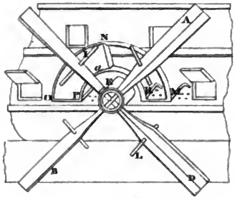

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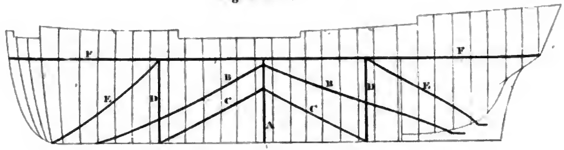

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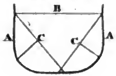

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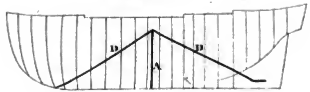

Elevated Longitudinal Section

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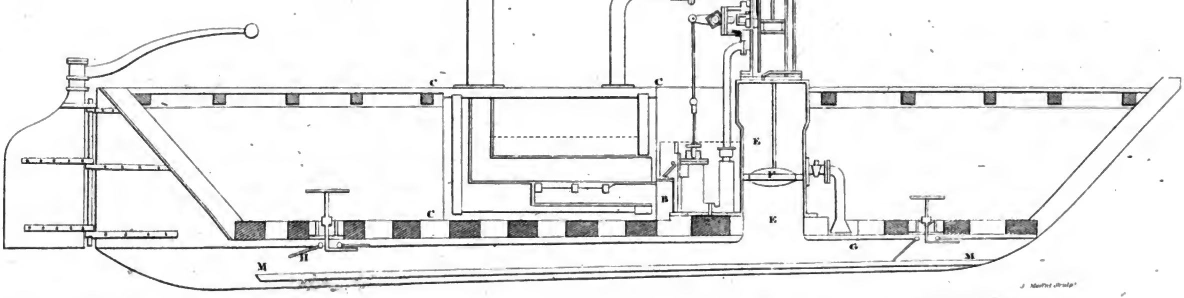

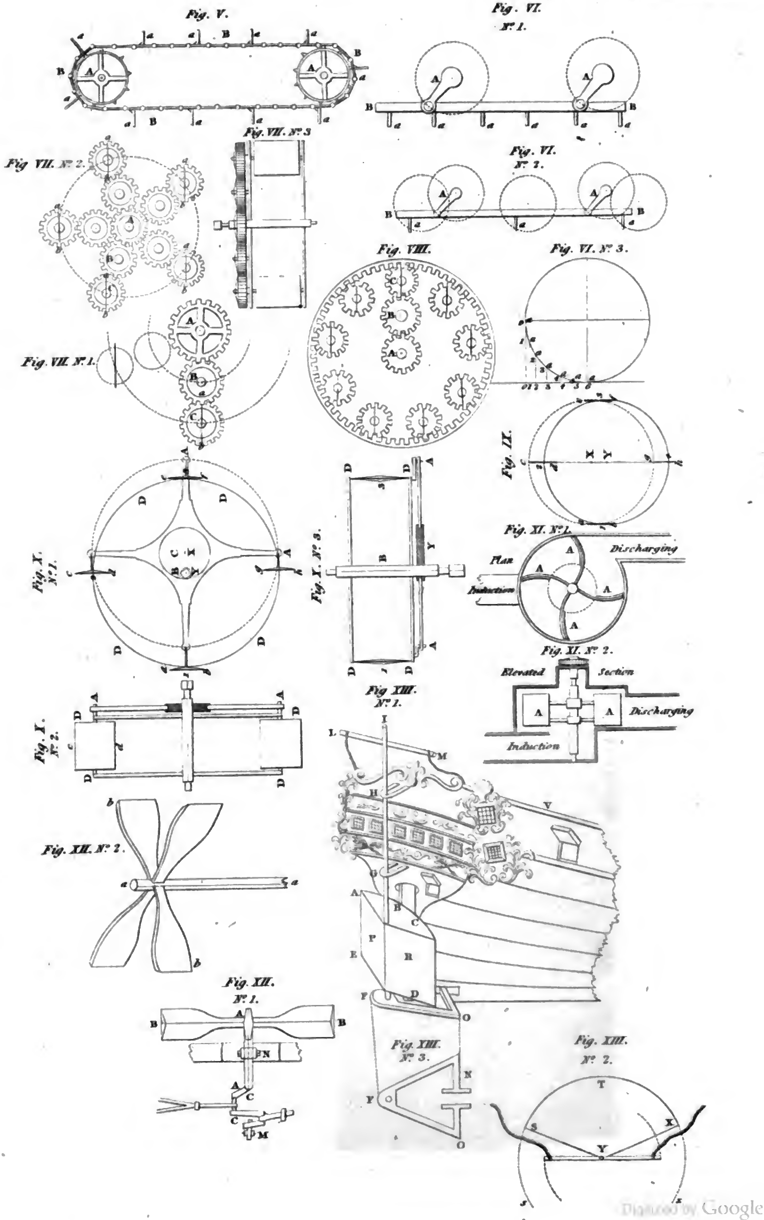

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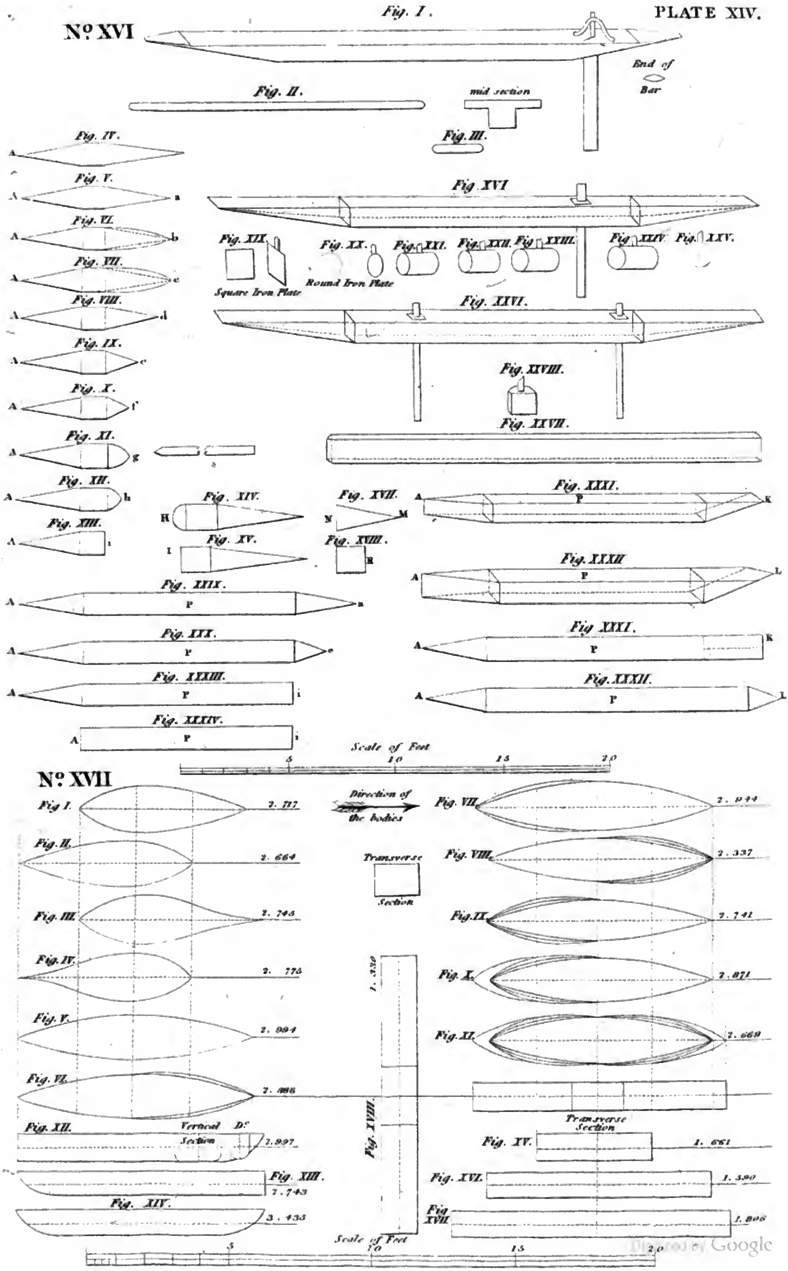

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Vertical Dº Section
Transverse Section
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2. 664
2. 745
2. 775
2. 904
2. 888
2.997
2. 743
3. 435
2. 944
2. 337
2. 741
2. 871
2. 669
1. 661
1. 390
1. 896
1. 330
Scale of Feet
5
10
15
20

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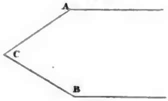


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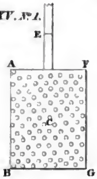


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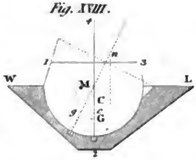


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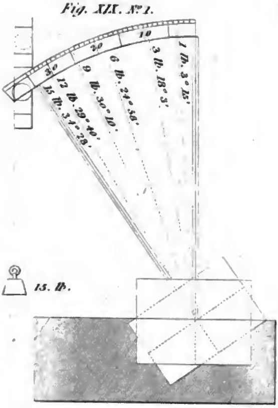


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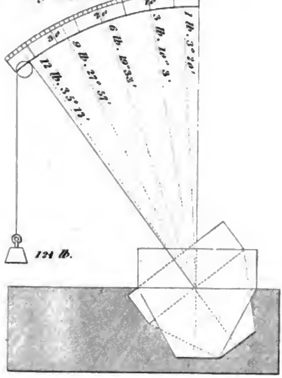


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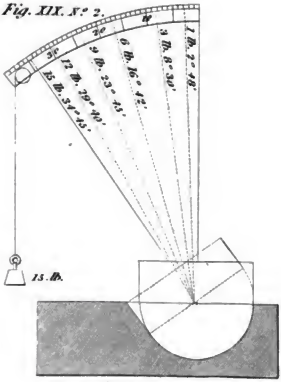


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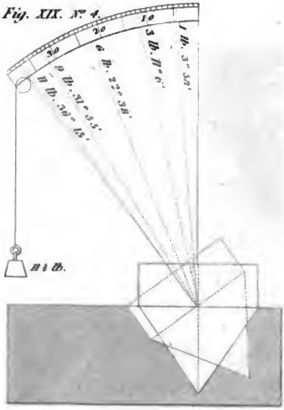
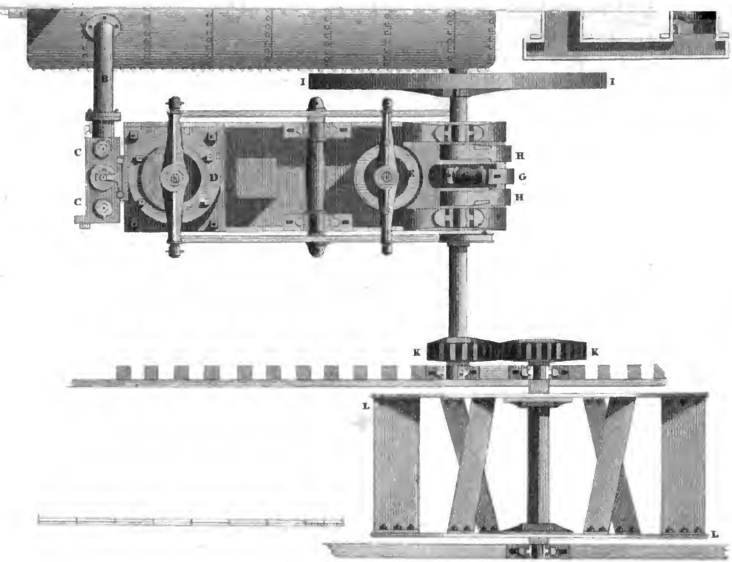



Drawn by R. Buchanan

R. Kirkwood Sculp.

PLATE XVI.




Drawn by R. Buchanan

R. Kirkwood Sculp.

*Fig. XIV.*
*No. 2.*

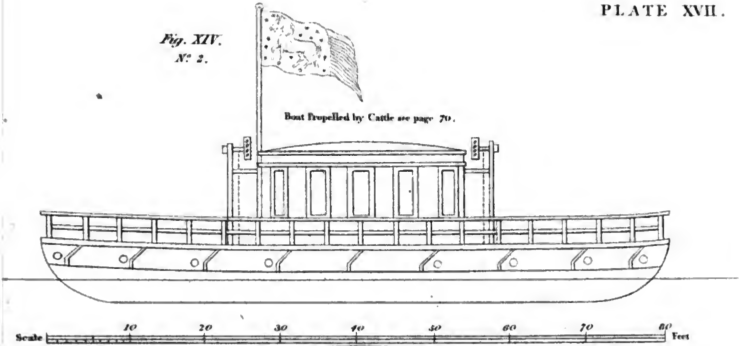



*Fig. XIV.*
*No. 1.*

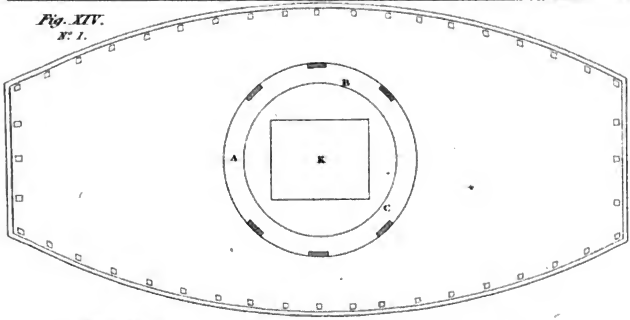



*Fig. XIV.*
*No. 3.*

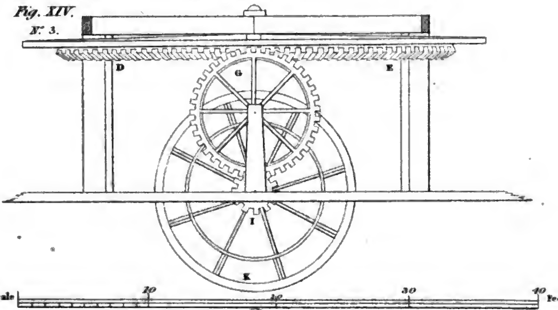
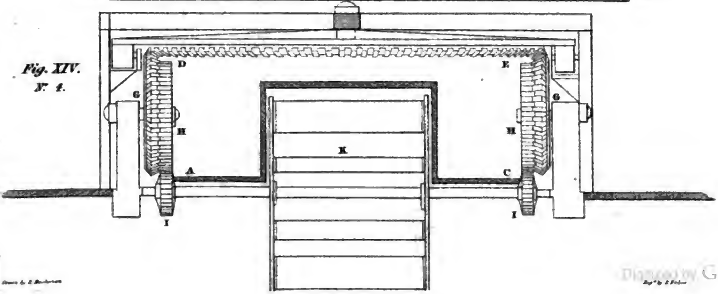



*Fig. XIV.*
*No. 4.*



D7.

Jw